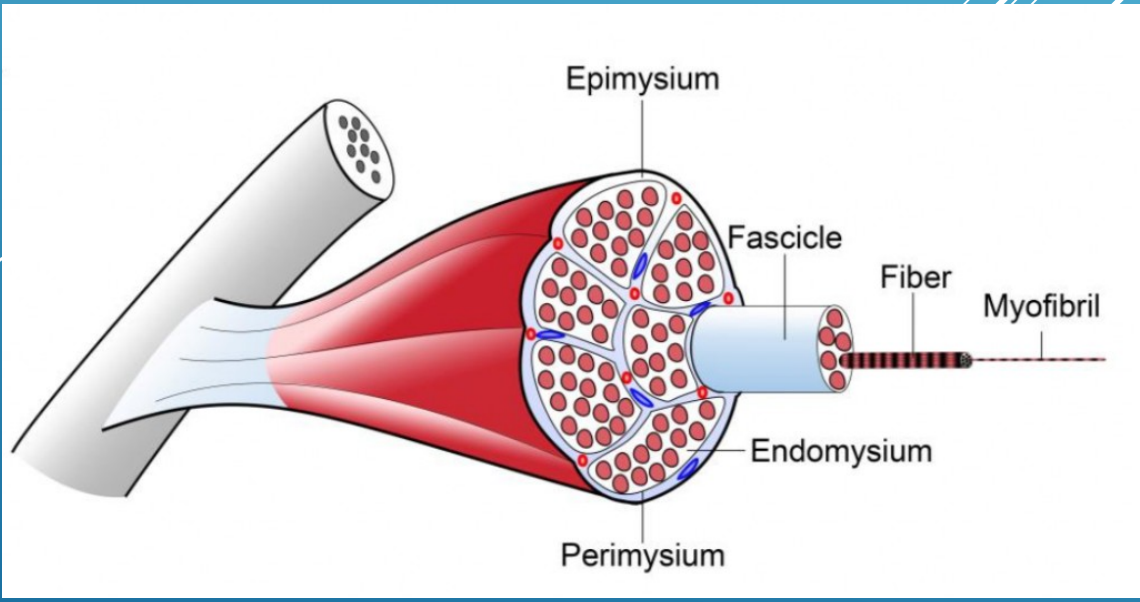
MUSCLE TISSUE

At the end of the lesson, the student:

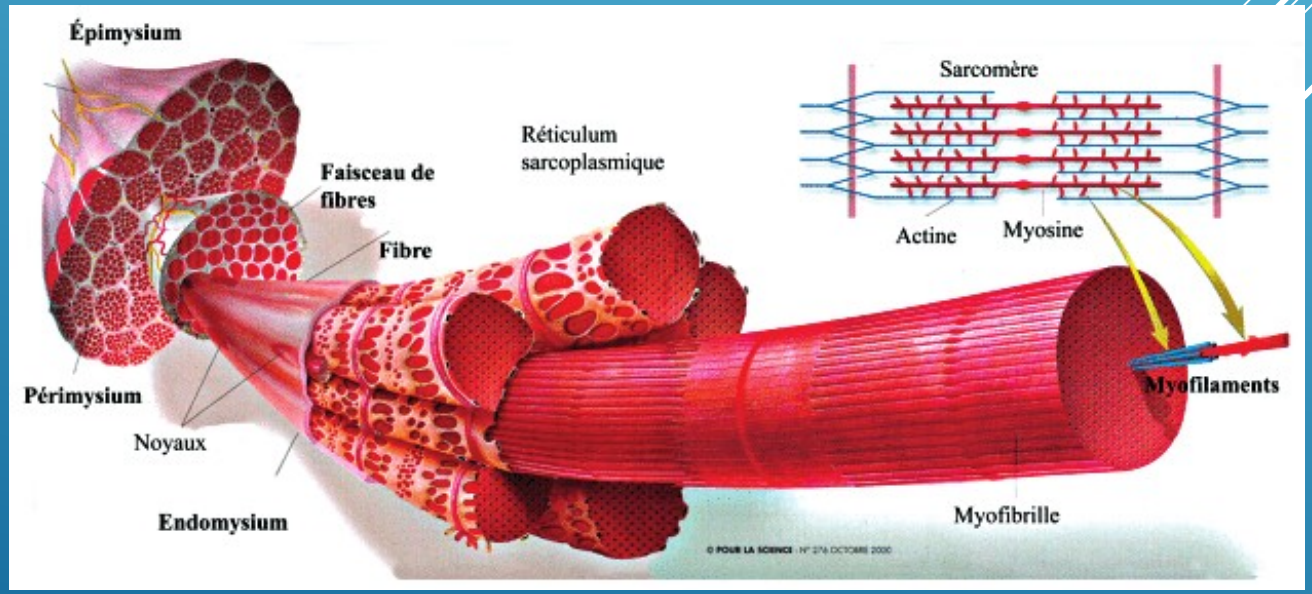
- Counts the features that distinguish muscle tissue from other tissues
- Classifies muscle tissue
- Defines the microscopic properties of striated skeletal muscle fibers
- Explains the striation mechanism of skeletal muscle
- Counts the locations and functions of auxiliary proteins of skeletal muscle
- Explains the contraction mechanism of skeletal muscle
- Counts the connective tissue layers that support the skeletal muscle
- Defines the types of skeletal muscle fibers and their properties
- Describes the parts of the engine endplate and the features of these parts.
- Describes the regeneration of skeletal muscle
- Defines microscopic features of striated cardiac muscle cells and fibers
- Explains the striation mechanism of the heart muscle
- Tells the regeneration of the heart muscle

- Muscle tissue is responsible for the movement of the body, the change of shape and size of internal organs, body position and temperature stabilization.
- Muscle tissue has the ability to contract, stimulane, stretch, and provide flexibility.
- Muscle is a tissue made up of cells that can convert chemical energy into mechanical energy Orjin of muscle is mesoderm.

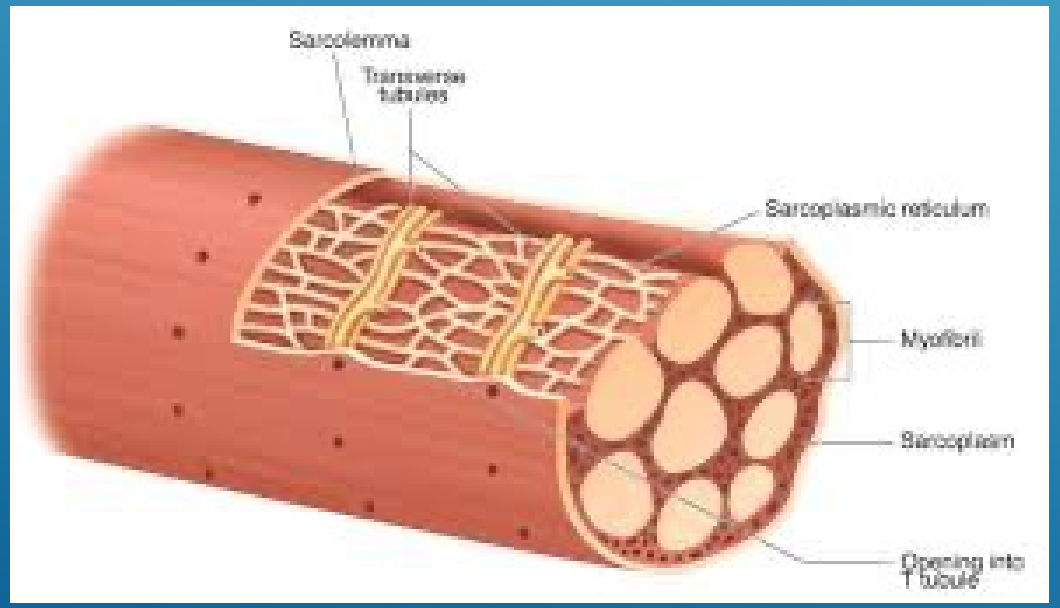
Sarcolemma: muscle cell membrane
Sarcoplasm: muscle cell cytoplasm
Sarcoplasmic reticulum: smooth endoplasmic reticulum
Sarcosome: Muscle cell mitochondrion
Sarcomere: the contractile unit of the muscle
Muscle fiber: Muscle cell (**myocyte)**

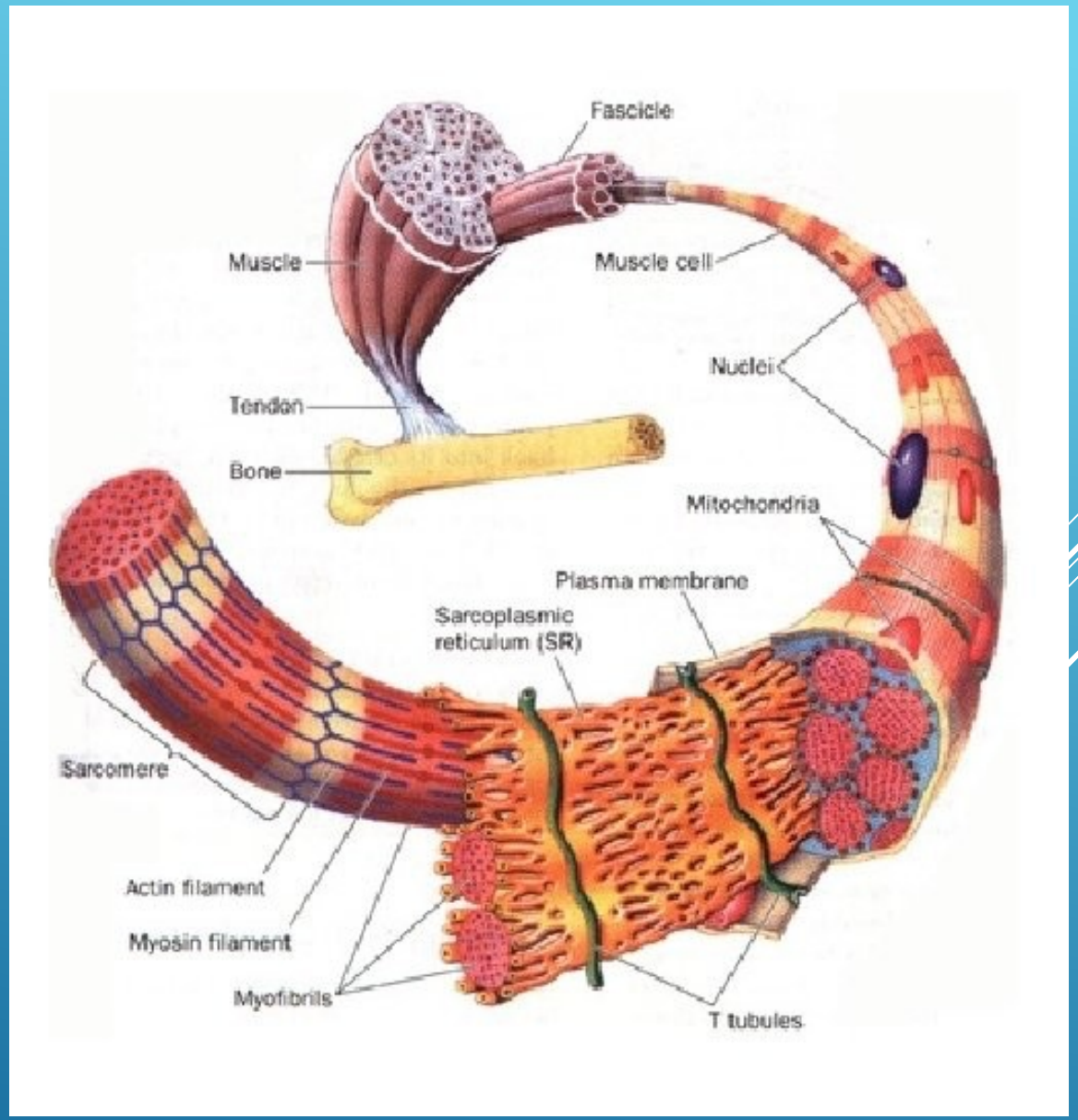


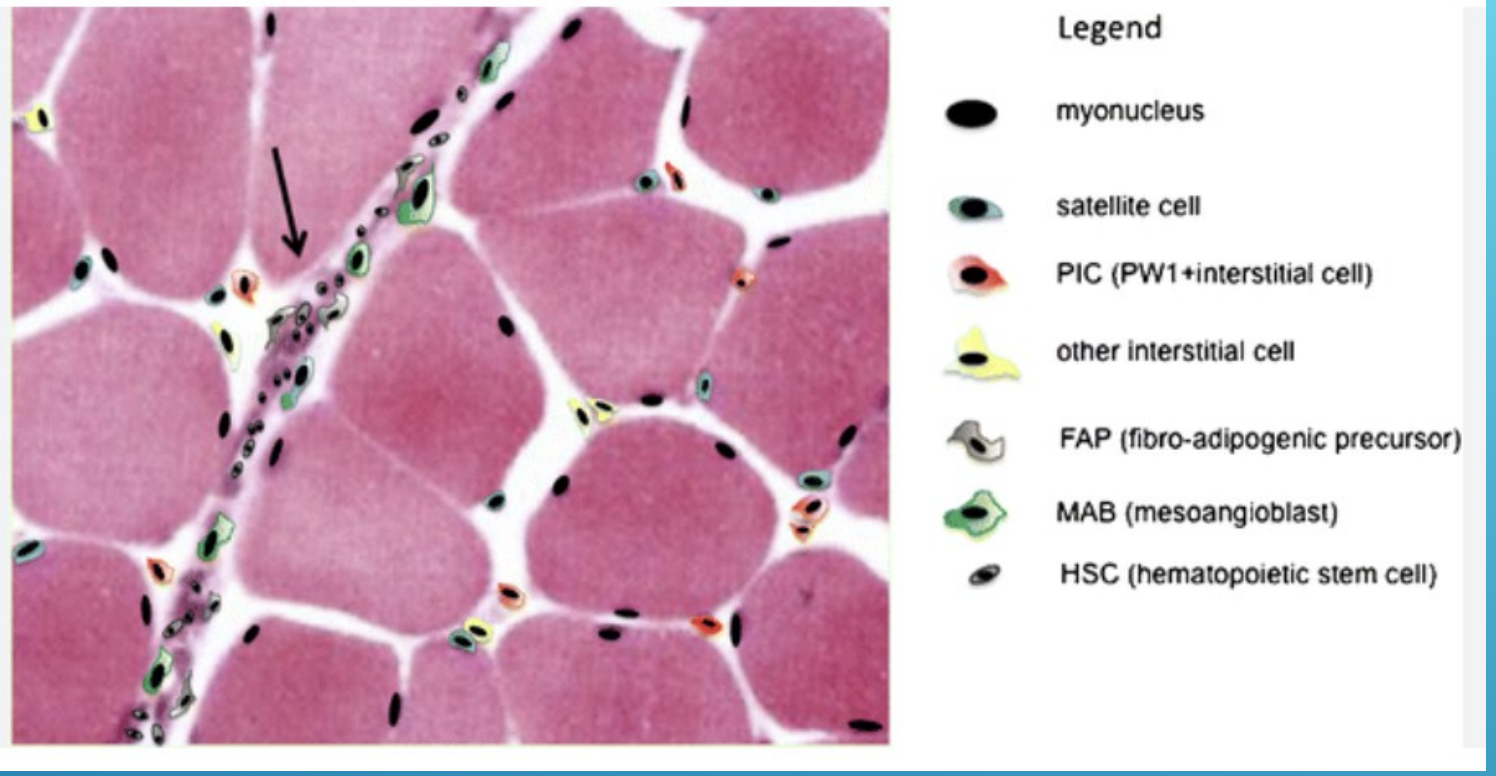
- Each muscle cell is called **myocyte**.
- Myocyte (muscle fiber) contains proteins called **myofilaments**, which have contraction properties.
- Myofilaments combine to form **myofibril**.

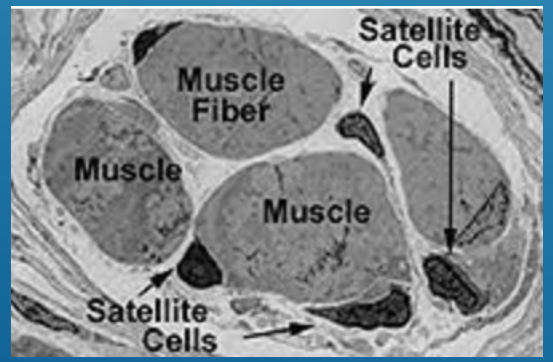


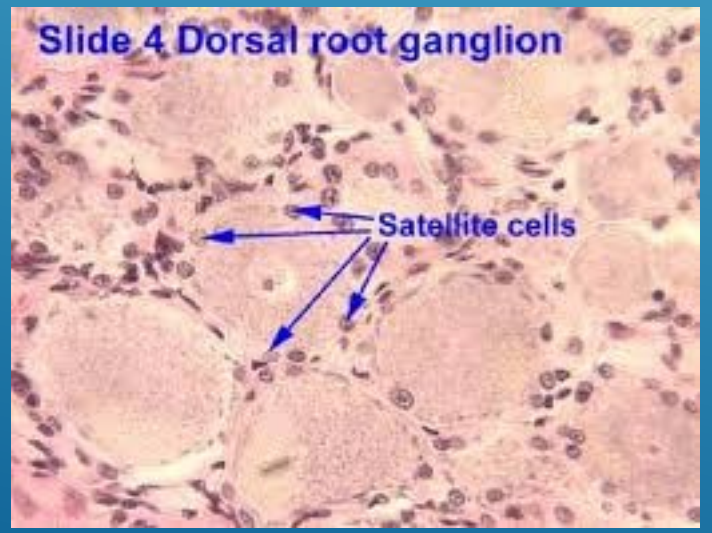
The membranes of muscle fibers are called **sarcolemma**, cytoplasm **sarcoplasma**, endoplasmic reticulum **sarcoplasmic reticulum** and mitochondria **sarcozom.**



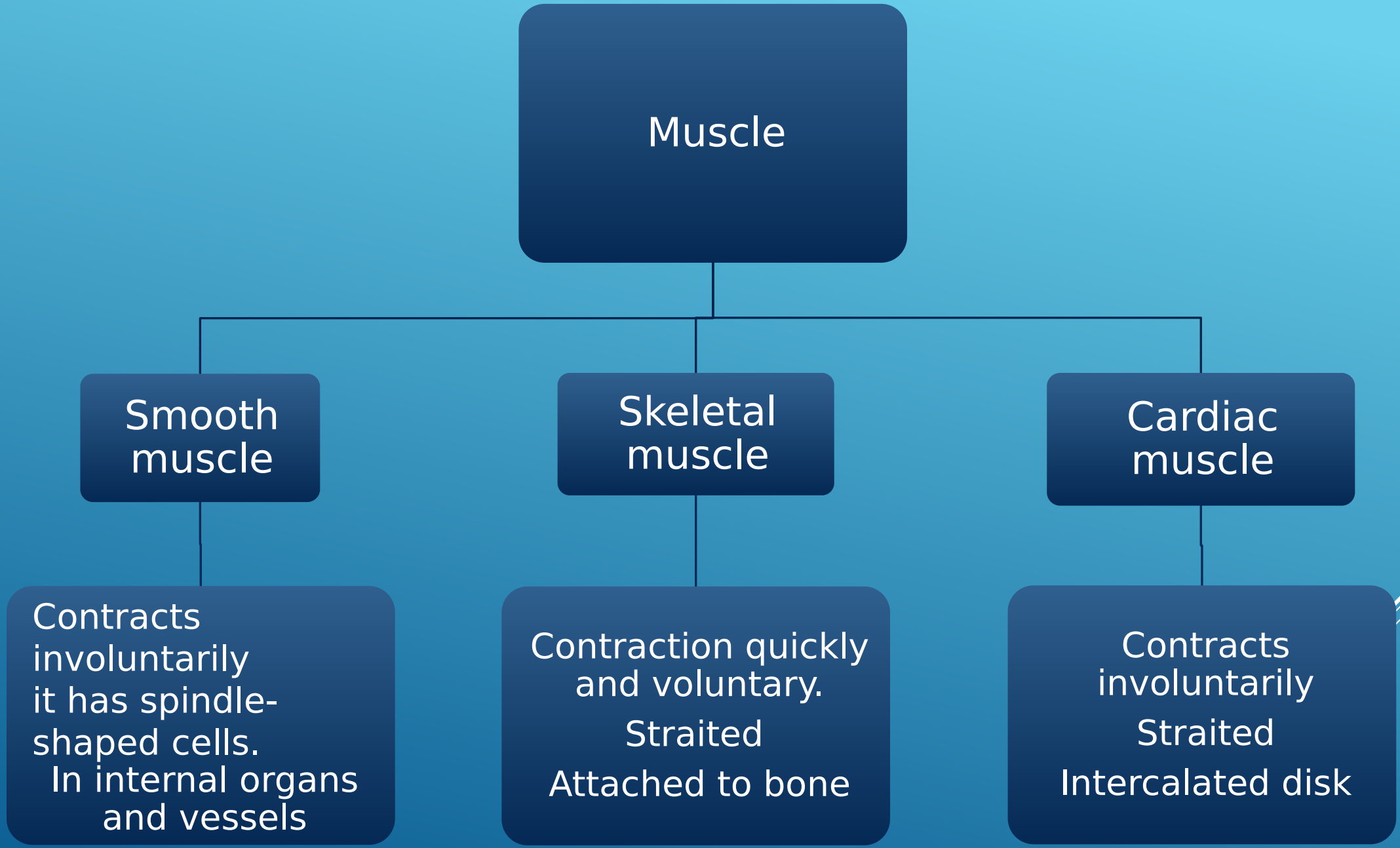




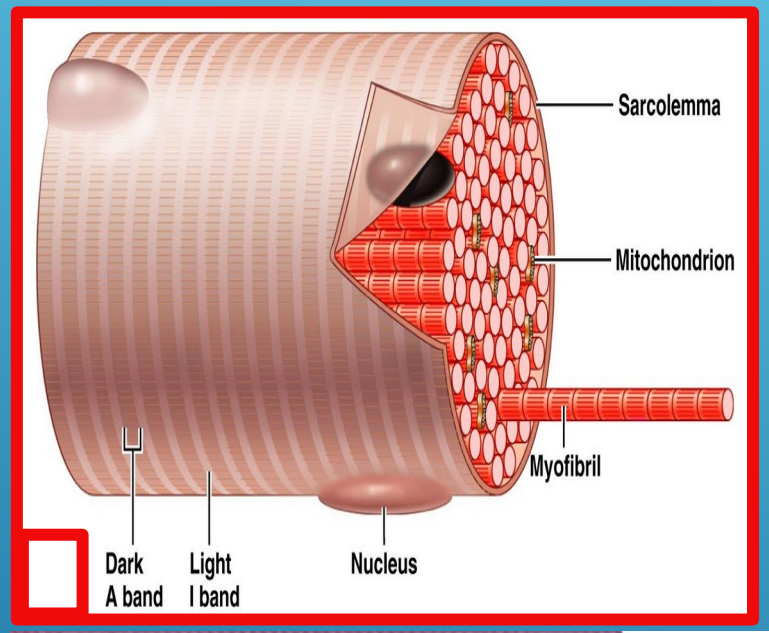


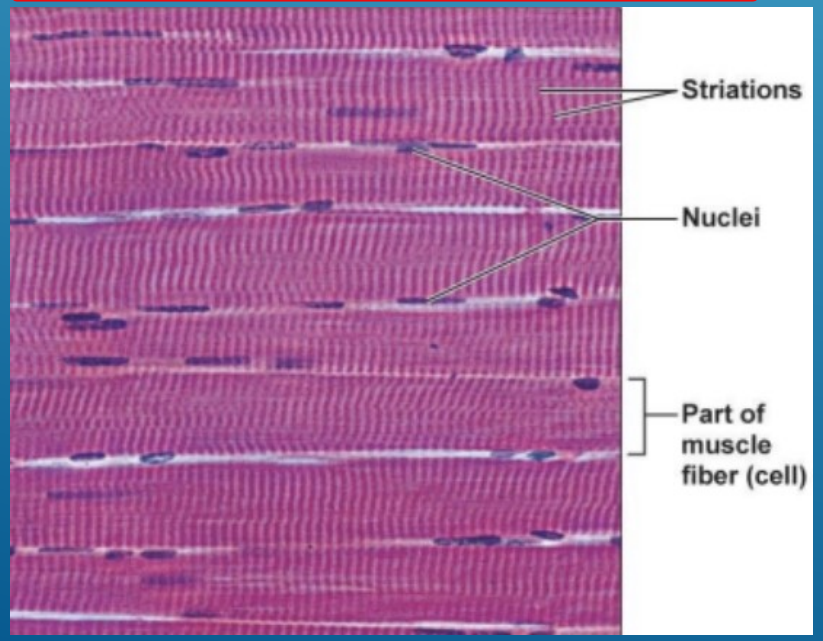


- Between the muscle cells are progenitor cells called satellite cells.
- This cell plays a role in rejeneration.


Muscle
Smooth muscle
Skeletal muscle
Cardiac muscle
Contracts involuntarily it has spindle-shaped cells.
In internal organs and vessels
Contraction quickly and voluntary.
Straited
Attached to bone
Contracts involuntarily
Straited
Intercalated disk

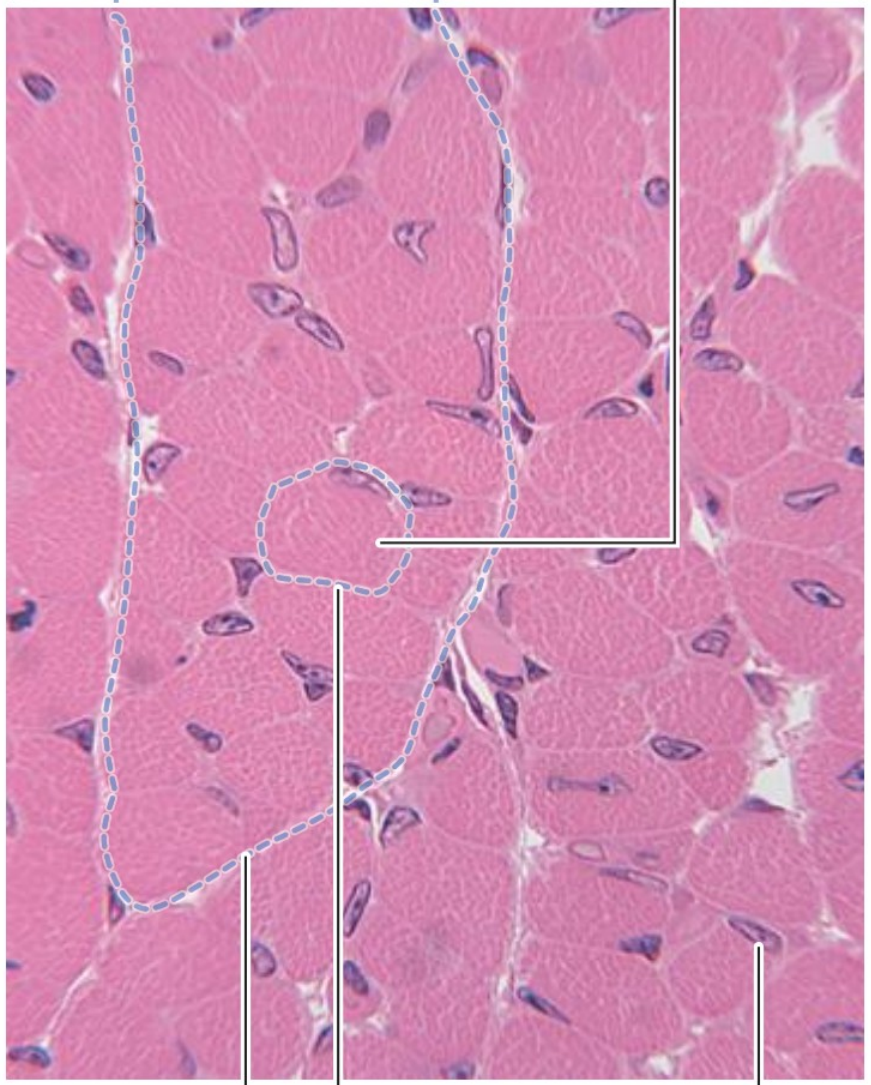
SKELETAL MUSCLE

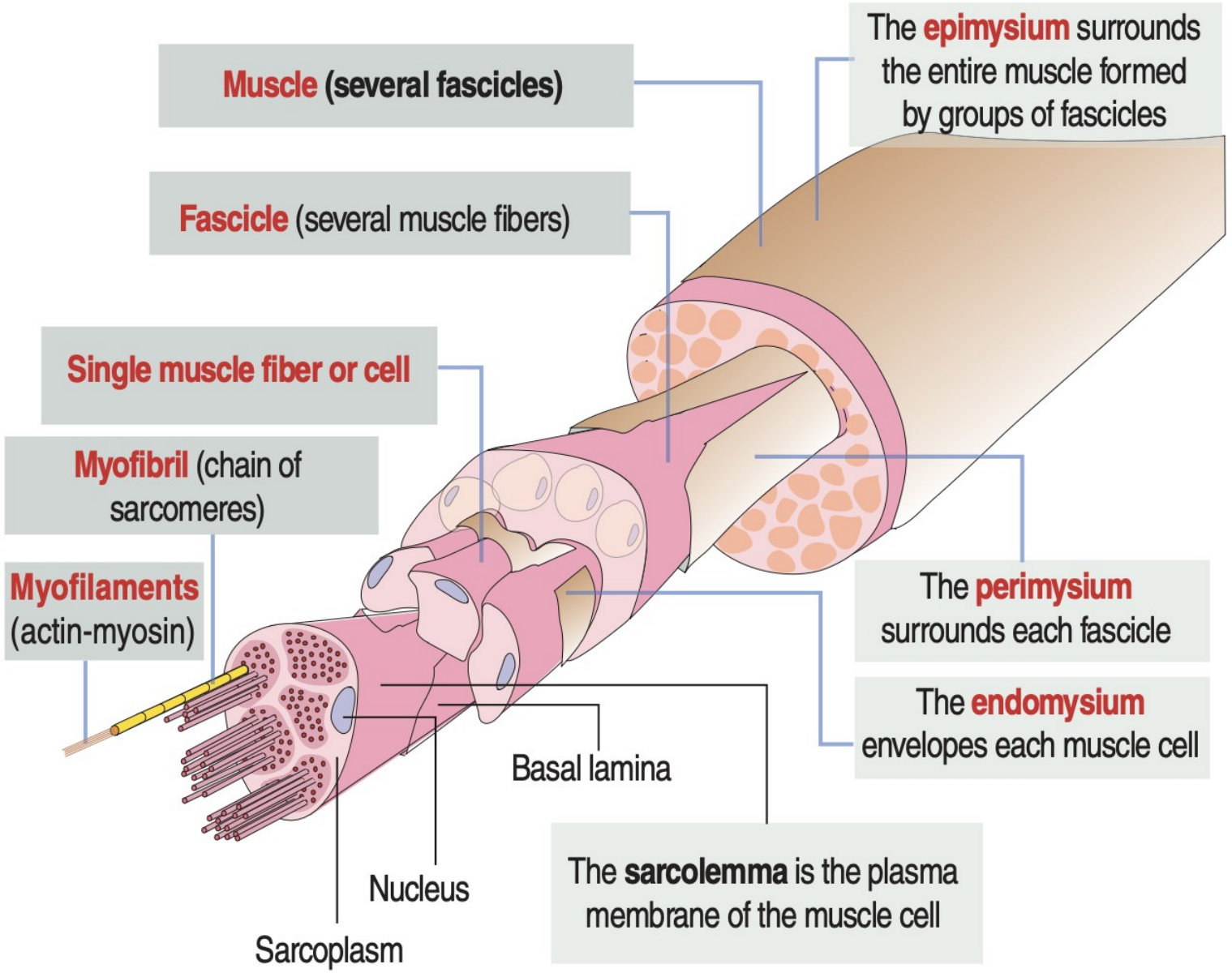




- Skeletal muscle consists of long, cylindrical multinucleated cells
- The long oval nuclei are usullay found at the periphery of the cell.
- They contract voluntarily.
- Contraction and relaxing fast, tire quickly.

Figure 7-1. General organization of the skeletal muscle


Cross section of a fascicle
Cross section of a muscle cell or fiber
Perimysium
Endomysium
Peripheral nucleus of a single muscle cell

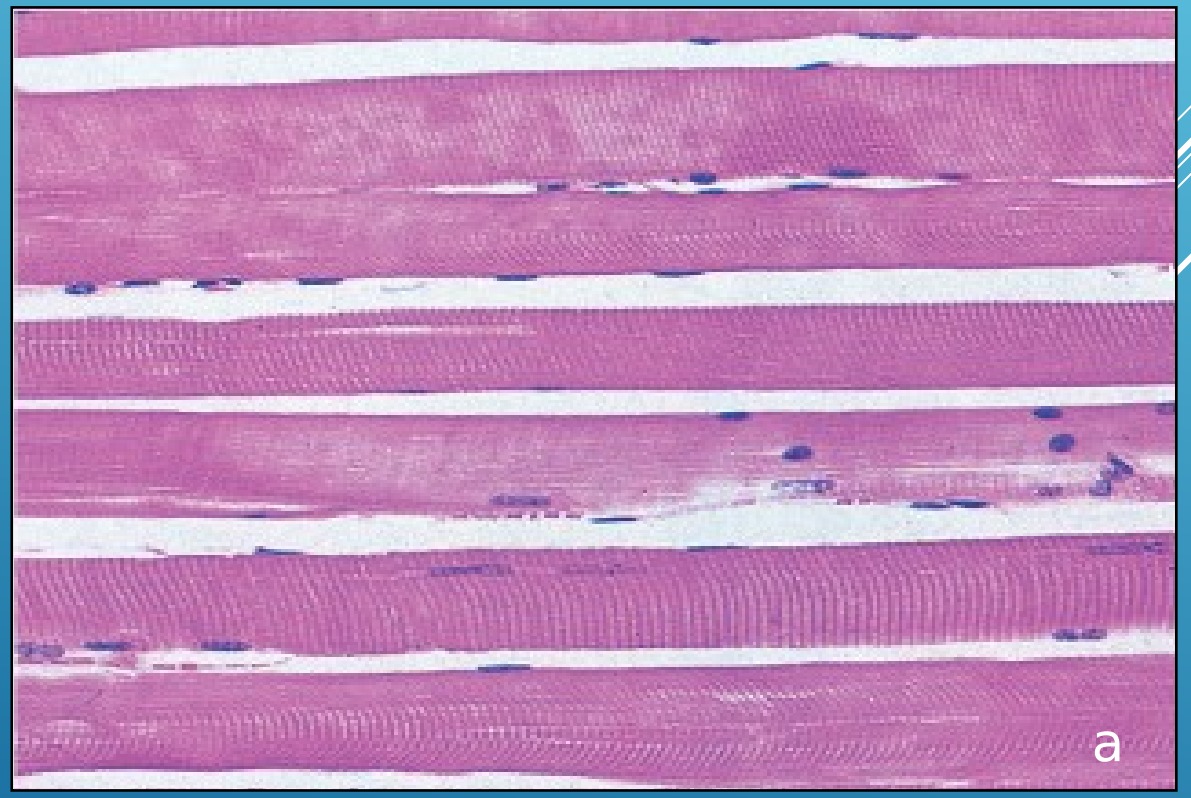

Muscle (several fascicles)
The epimysium surrounds the entire muscle formed by groups of fascicles
Fascicle (several muscle fibers)
Single muscle fiber or cell
Myofibril (chain of sarcomeres)
Myofilaments (actin-myosin)
The perimysium surrounds each fascicle
The endomysium envelopes each muscle cell
Basal lamina
The sarcolemma is the plasma membrane of the muscle cell
Nucleus
Sarcoplasm

- Thin and smallest myofibrils are called actin and thick ones are called the myosin. And they caused the striated appearance

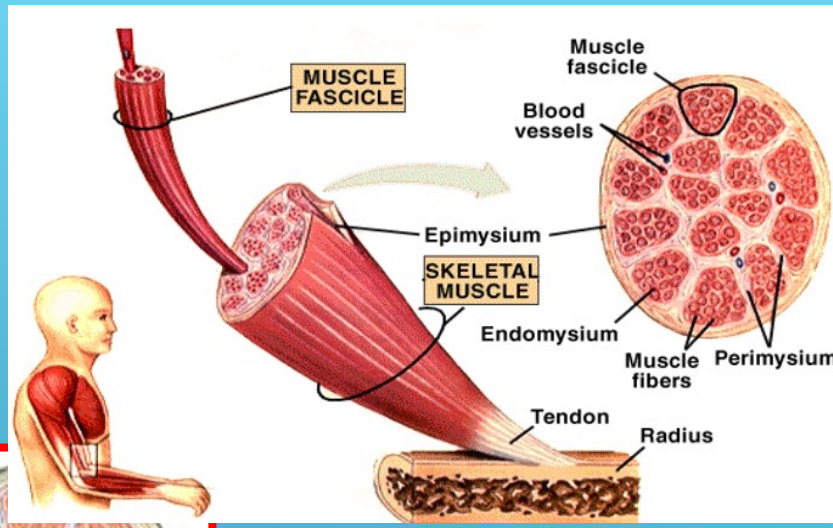
- The structural and functional subunit of the striated muscle fiber is the myofibril.

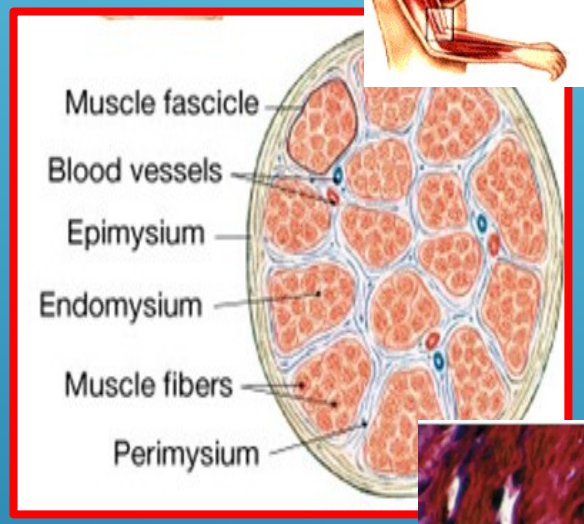
- Myofibrils are composed of myofilaments that contain special proteins responsible for the cell's ability to contract.

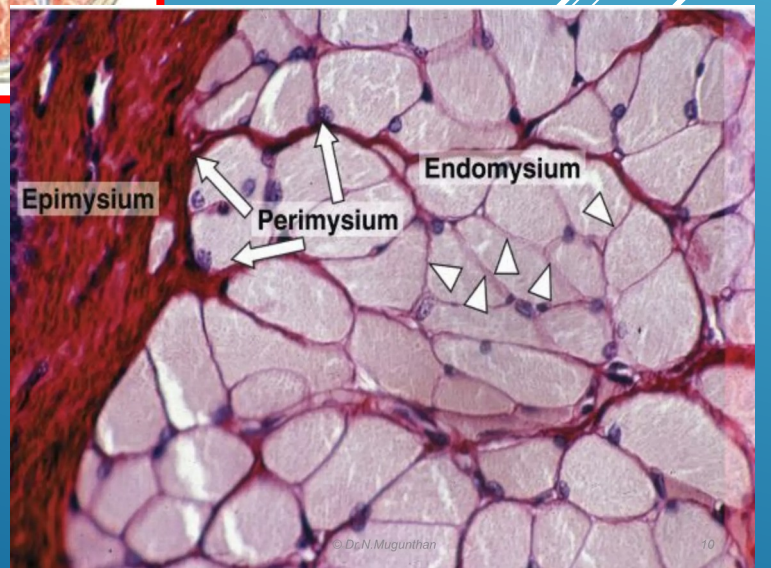
- Myofilaments are the main contractile elements of striated muscle and consist of thick filaments (myosin II) and thin filaments (actin and related proteins-troponin and



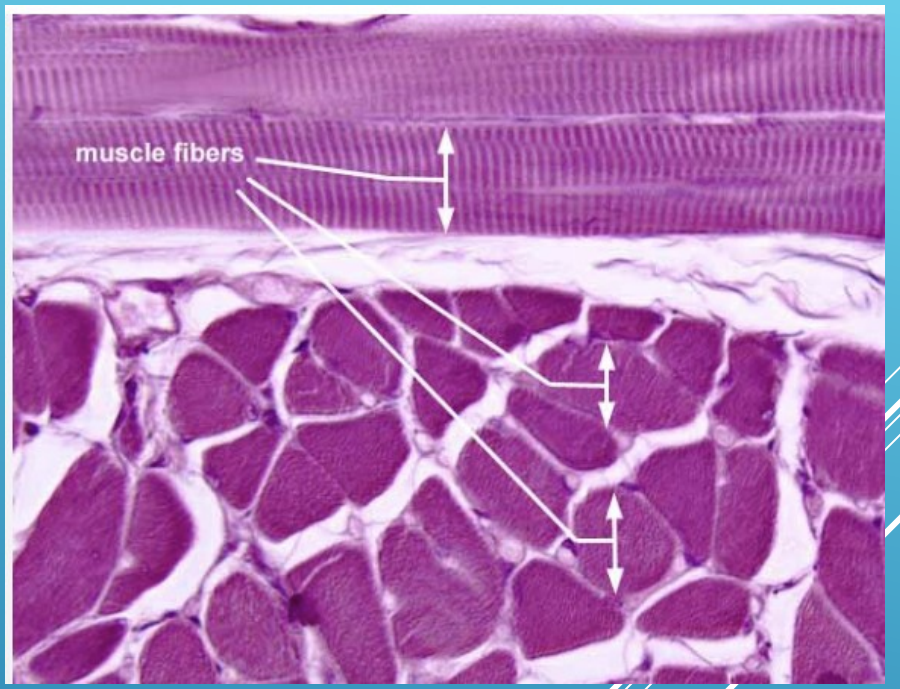
- **Epimysium**
- Entire muscle
- Dense irregular collagenous connective tissue. Septa of this tissue extend inward, carrying the larger nerves, blood vessels, and lymphatics of the muscle.
- **Perimysium**
- Less dense collagenous connective tissue derived from epimysium. Surrounds bundles (fascicles)
- **Endomysium**
- Reticular fibers and an external lamina (basal lamina) surrounds each muscle cell (fiber)







- As observed with the light microscope, muscle fibers show cross-striations of alternating light and dark bands. The darker bands are called **A bands**, the lighter bands are called **I bands**.
- In I band there are a dark transverse line **Z line**.
- The repetitive functional subunit of contractile apparatus, the **sarcomere**, extend from Z line to Z line and its about 2,5µm long.



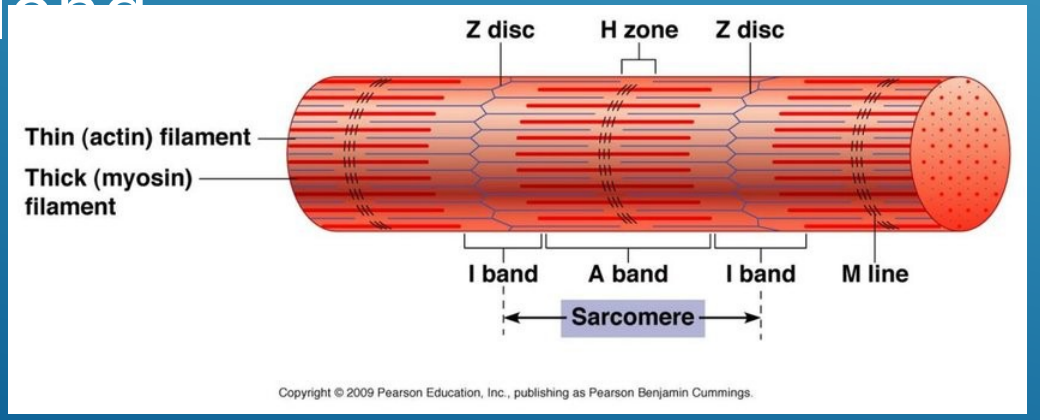
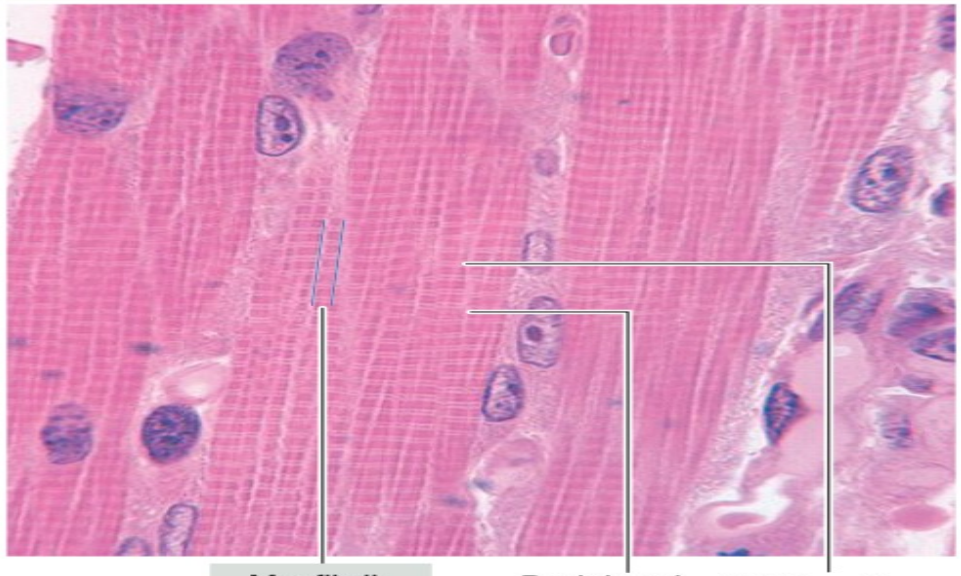
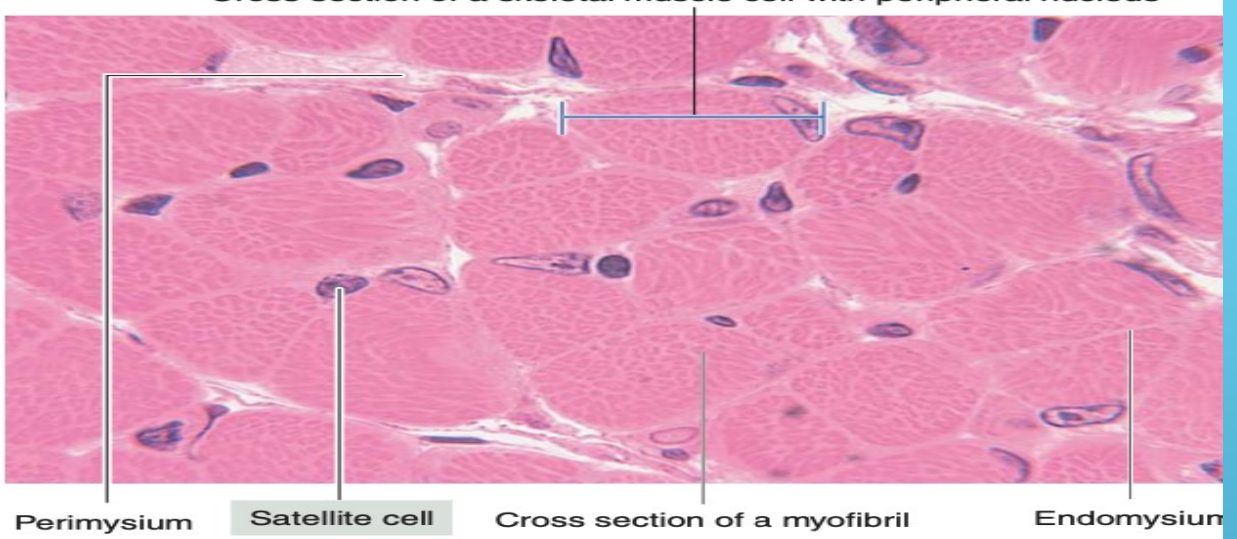


Figure 7-2. Skeletal muscle (striated)

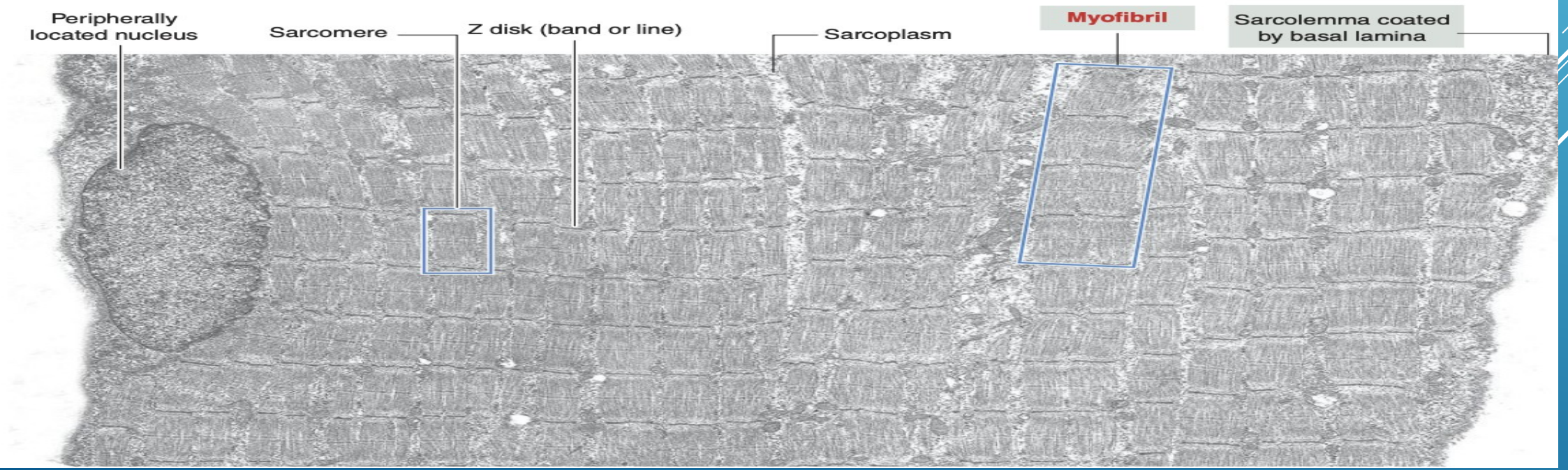
The cytoplasm of the muscle cell or fiber contains an elaborate and regular arrangement of **myofibrils**, each organizing alternating short segments of differing refractive index: **dark A bands and light I bands**.

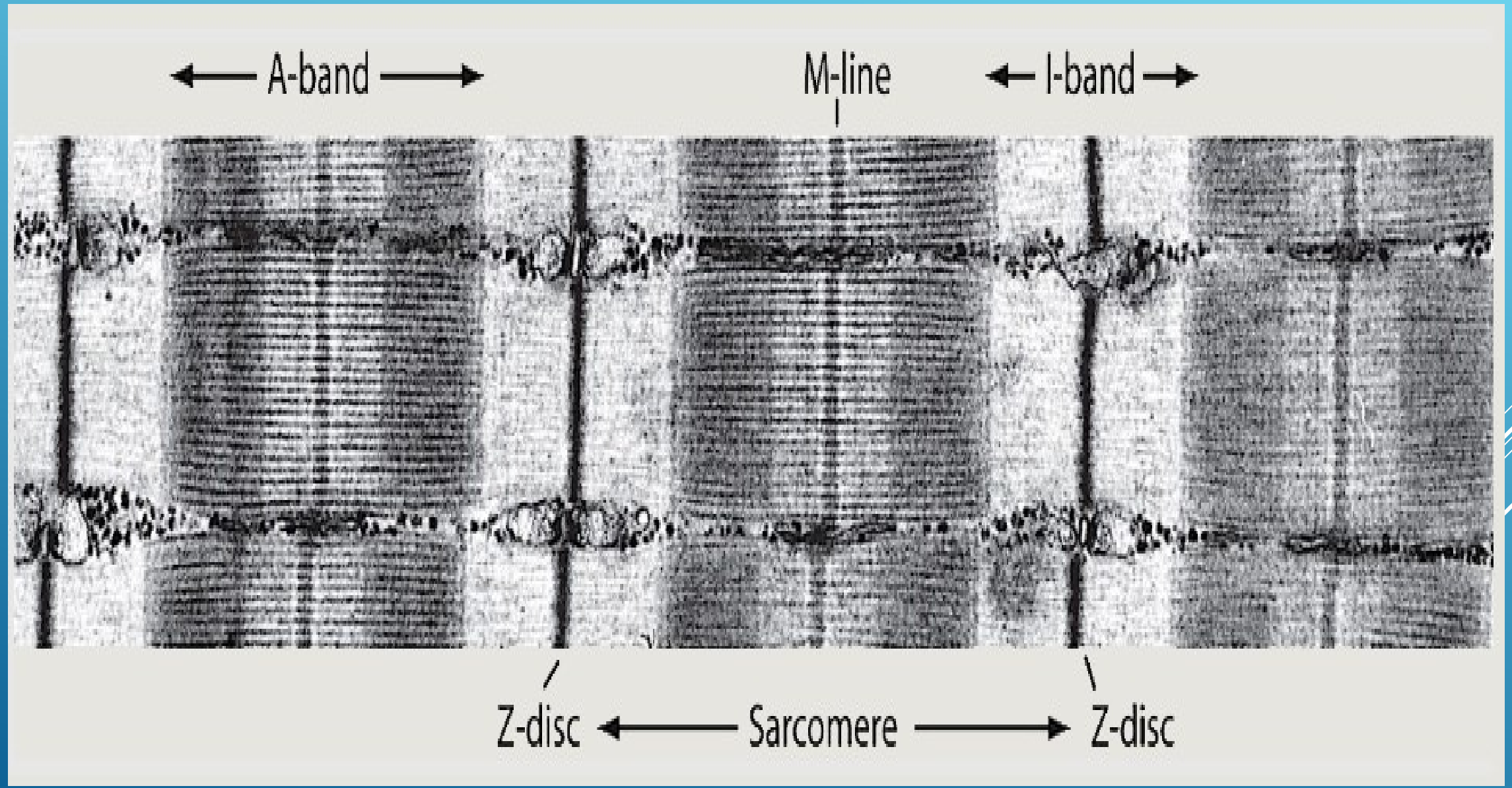


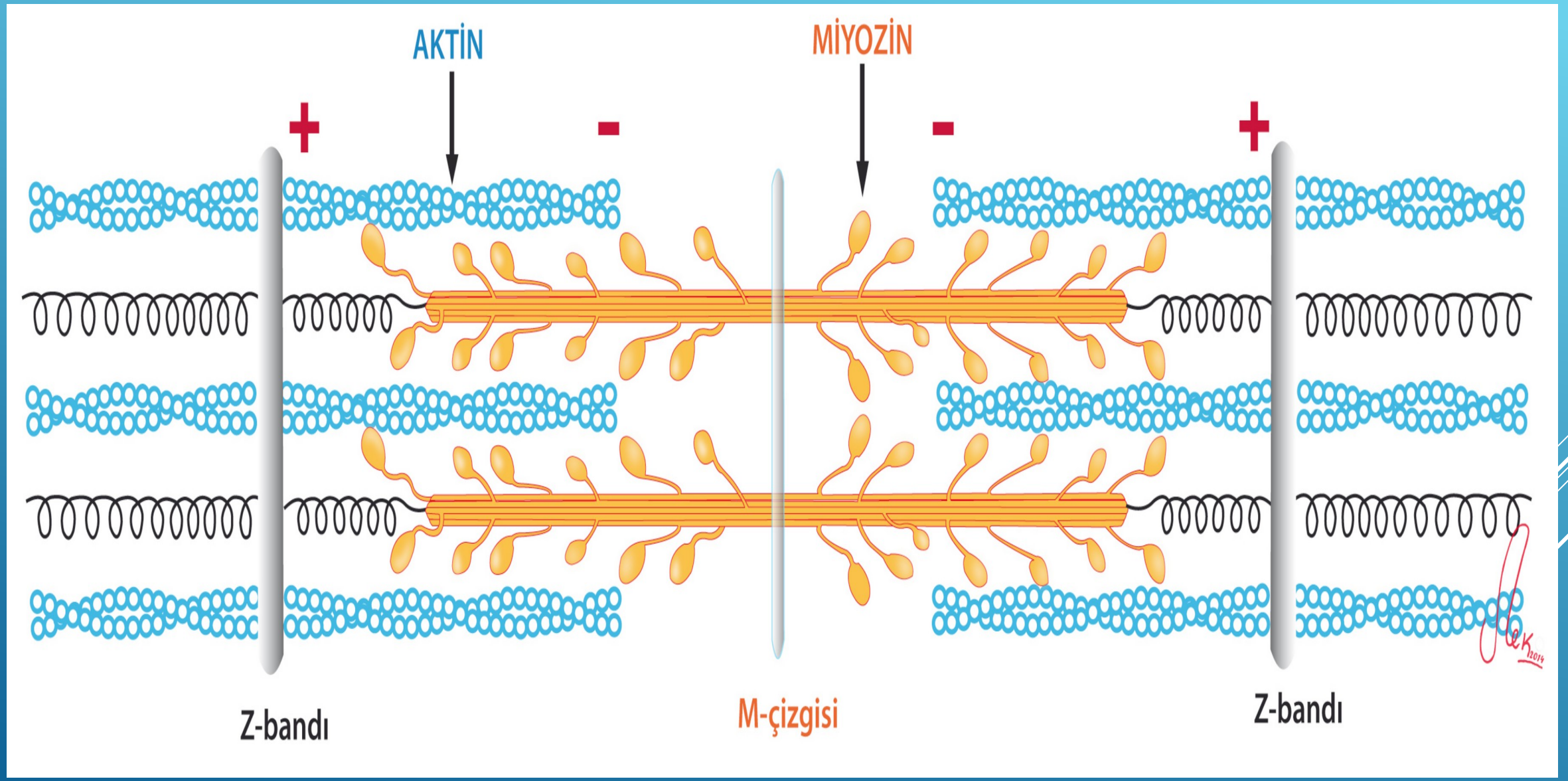
Cross section of a skeletal muscle cell with peripheral nucleus



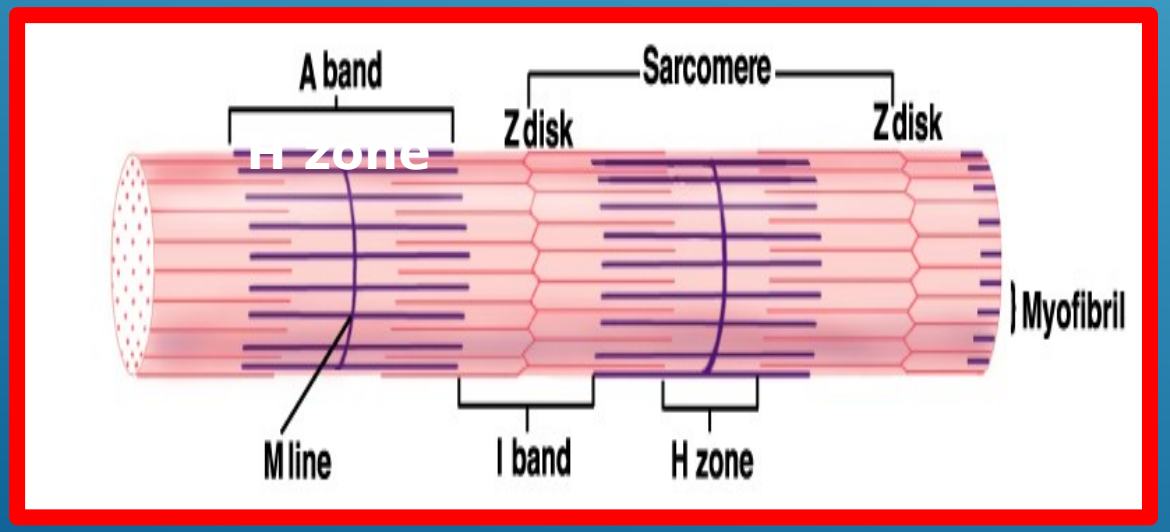
Myofilaments are components of a myofibril. There are two major classes of myofilaments: (1) the thin **actin** filaments; (2) the thicker **myosin** filaments. The cross-banded pattern of striated (skeletal or cardiac) muscle is due to the orderly arrangement of actin and myosin filaments. Actin is the predominant component of the I band. Myosin is the main component of the A band. I and A bands form a **sarcomere**, which extends between two adjacent Z disks.

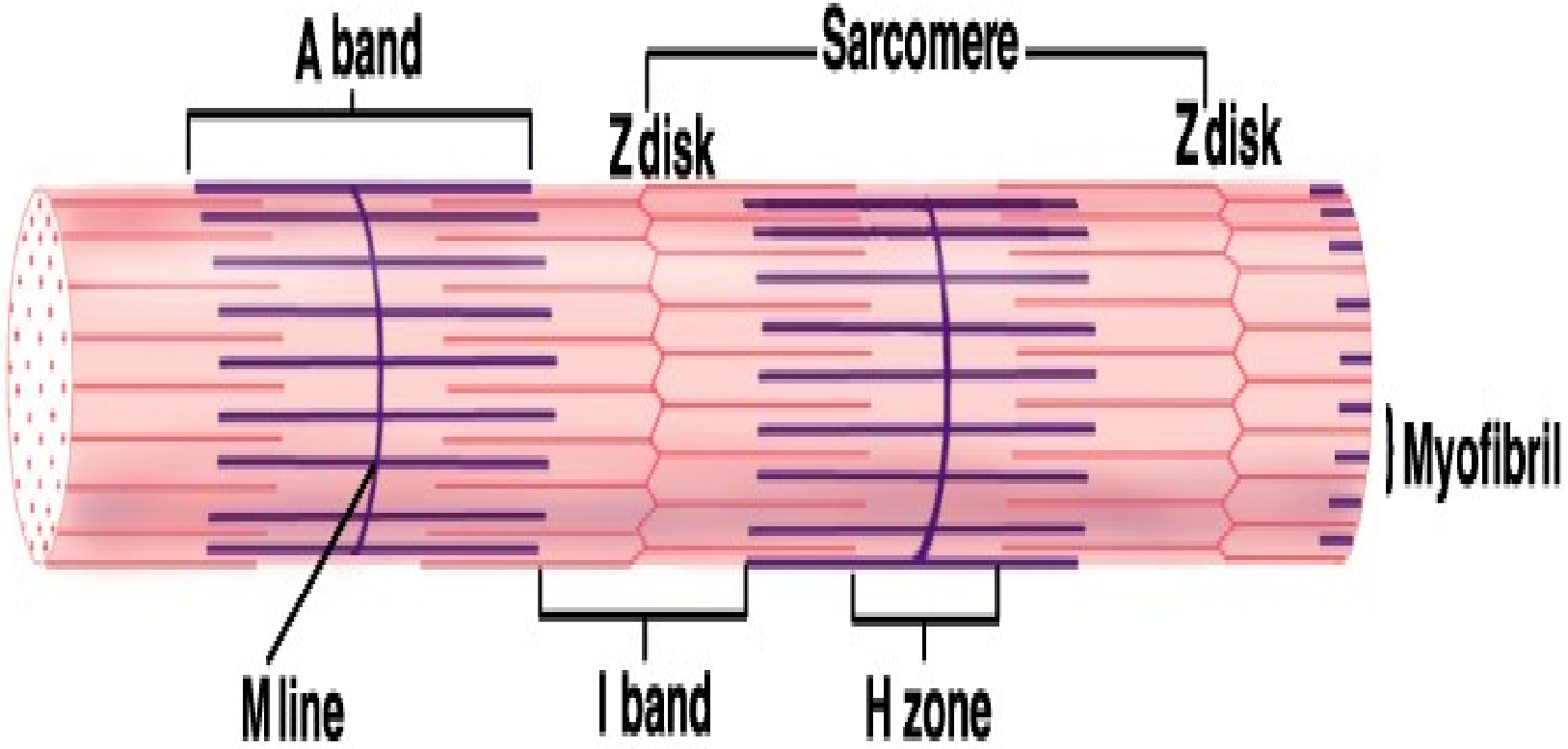



A-band
M-line
I-band
Z-disc
Sarcomere
Z-disc


AKTİN
MİYOZİN
+
-
-
+
Z-bandı
M-çizgisi
Z-bandı

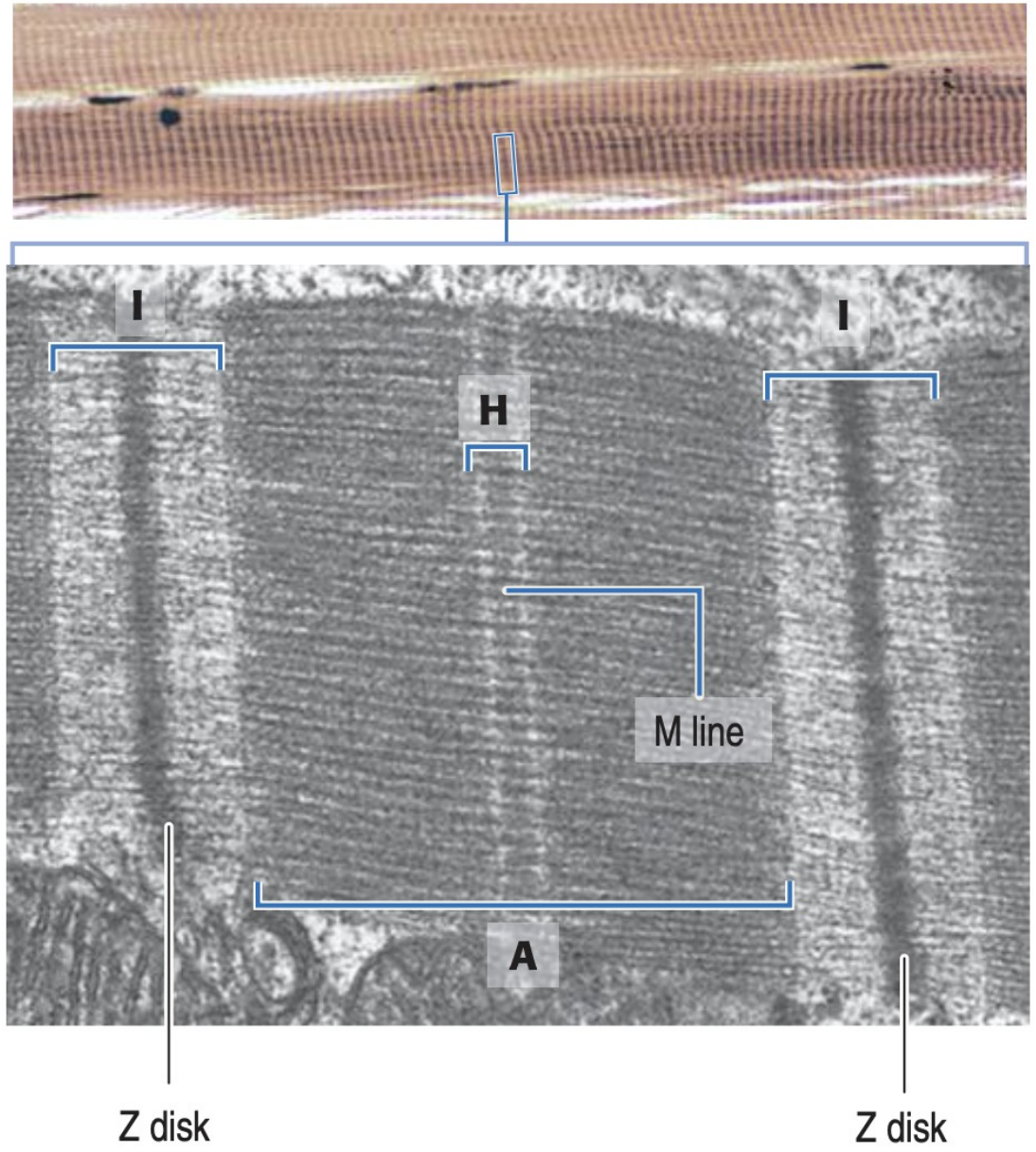
- **I bands** are made up of parts of thin filaments that do not overlap thick filaments.
- The **A band** is mainly composed of thick filaments and overlapping parts of thick filaments with thin filaments.
- In the middle of the A band, there is a more lightish area called the **H band**. This is just an area made up of rod-like parts of the myosin molecule.

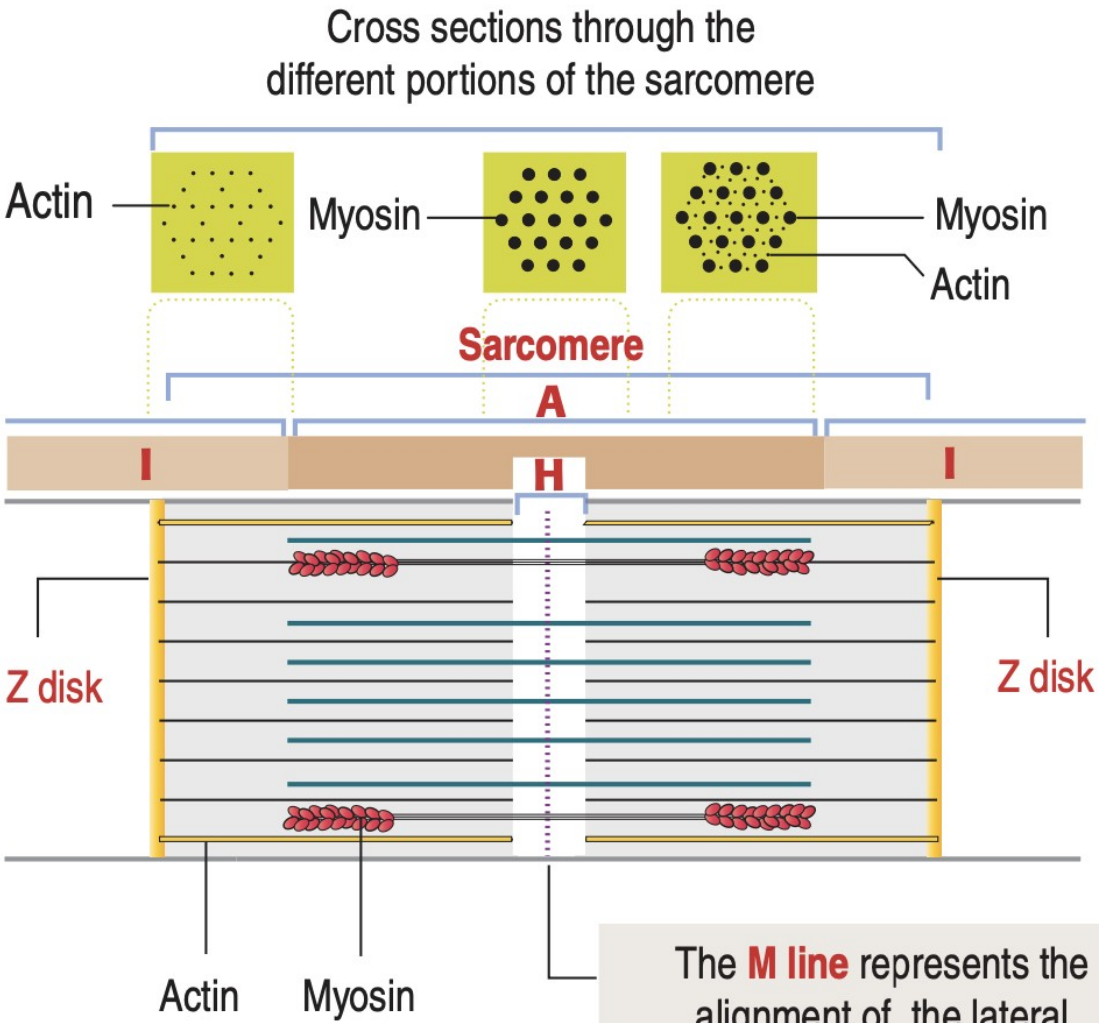




- The H band is divided into two by the **M line**. The M line is the region of side connections between adjacent thick filaments.

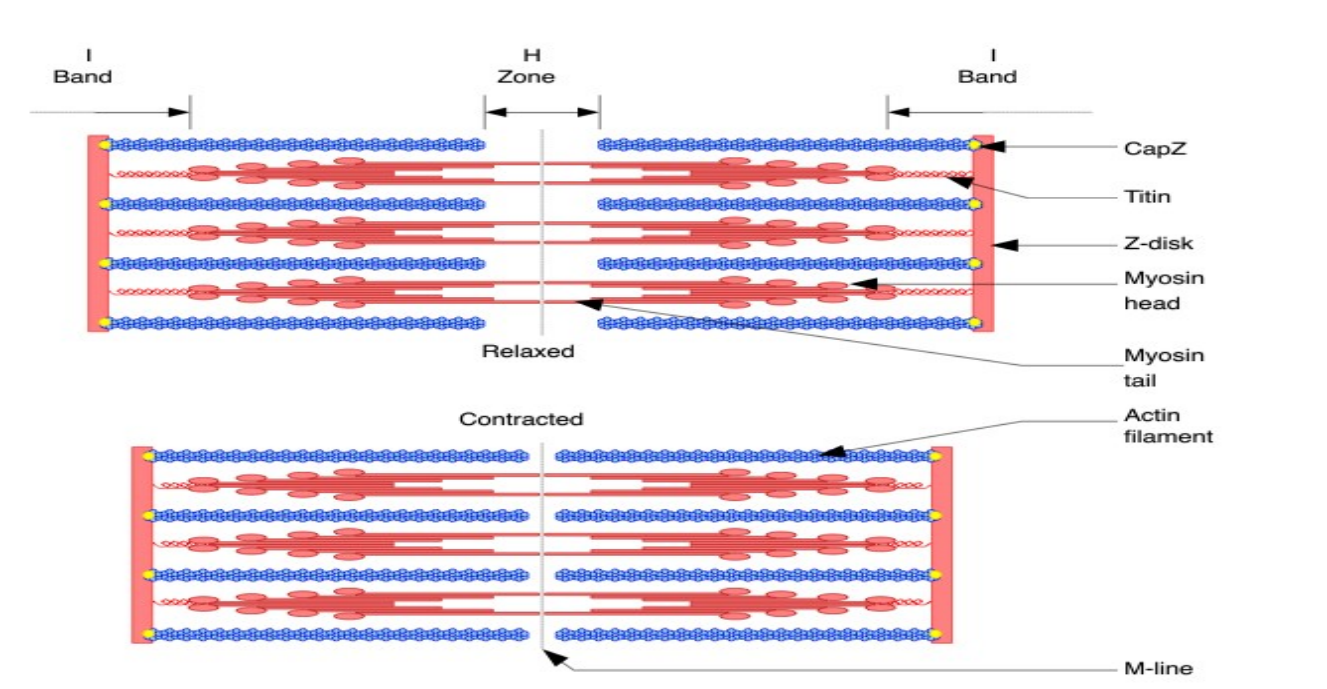
Figure 7-3. Sarcomere





The **M line** represents the alignment of the lateral assembled tails of myosin. The M line transects the pale **H band** at the middle of the A band.

- Skeletal muscle contraction is rapid, strong and voluntary.
- This is caused by the reciprocal movement of thick myosin filaments and thin actin filaments, allowing molecular structures to slide over each other.



Components of the thin and thick filaments of the sarcomere

F-actin, the thin filament of the sarcomere, is double- stranded and twisted. F-actin is composed of globular monomers (G-actin) G-actin monomers bind to each other in a head-to-tail fashion, giving the filament polarity, with barbed (plus) and pointed (minus) ends. The barbed end of actin filaments inserts into the Z disk.

F-actin forms a complex with tropomyosin and troponins.

Tropomyosin runs in the groove formed by F-actin strands.

Troponin is a complex of three proteins: **troponin I**, **C**, and **T**.

1. **Troponin T** binds the complex to tropomyosin.
2. **Troponin I** inhibits the binding of myosin to actin.

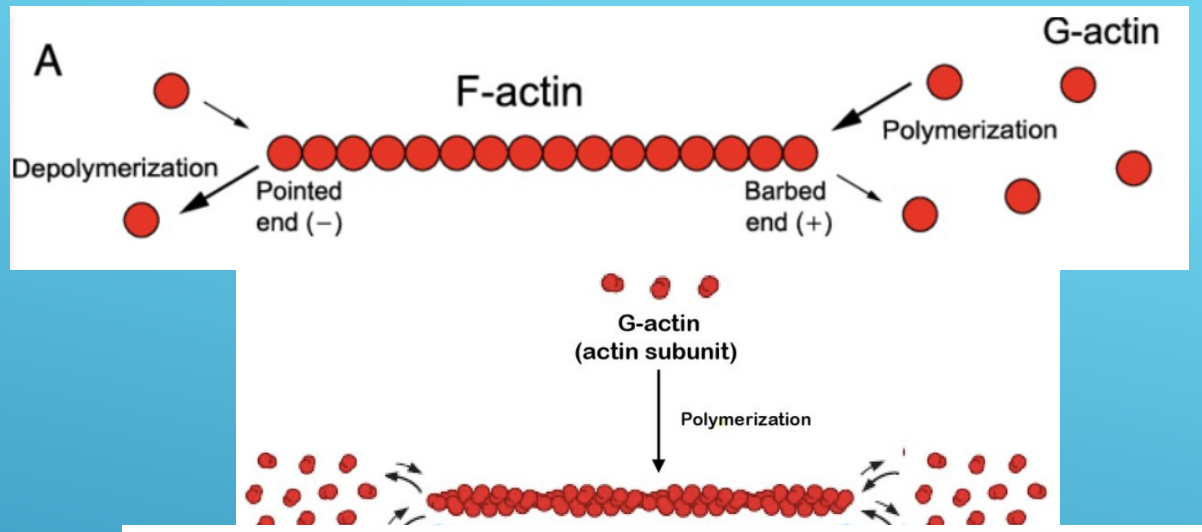
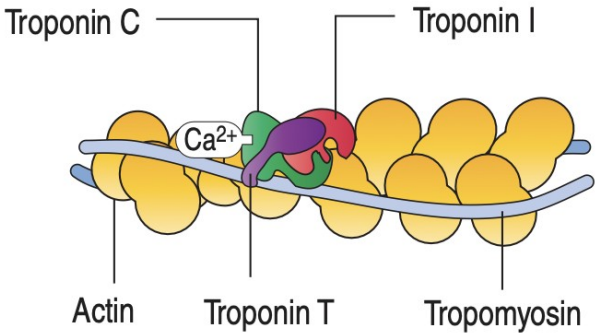


Figure 7-5. Troponin and tropomyosin

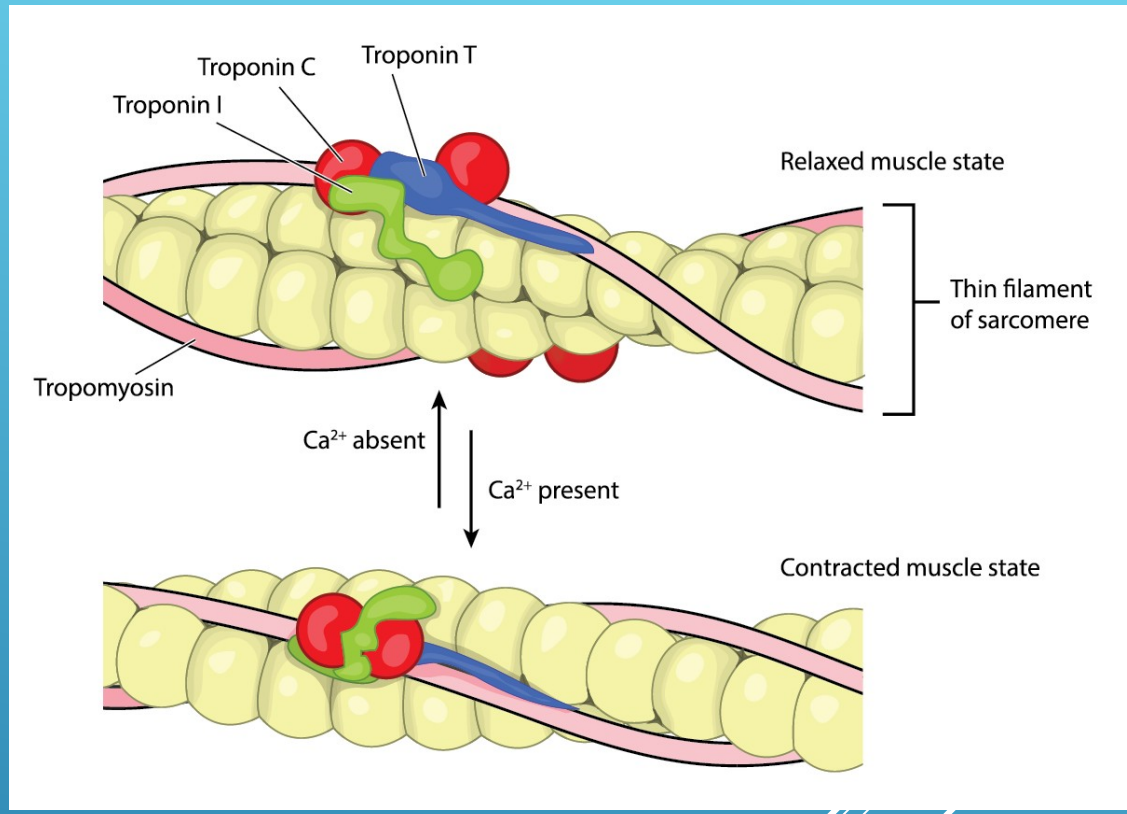


The troponin-tropomyosin-actin complex

Tropomyosin consists of two nearly identical α-helical polypeptides twisted around each other. Tropomyosin runs in the groove formed by F-actin strands. Each molecule of tropomyosin extends for the length of seven actin monomers and binds the troponin complex.

Troponin is a complex of three proteins: **troponin I**, **C**, and **T**. Troponin T binds the complex to tropomyosin. Troponin I inhibits the binding of myosin to actin. Troponin C binds Ca^{2+} and is found only in striated muscle.

- The energy (ATP) required for muscle contraction is provided by **creatine kinase**, the main protein of the M line.

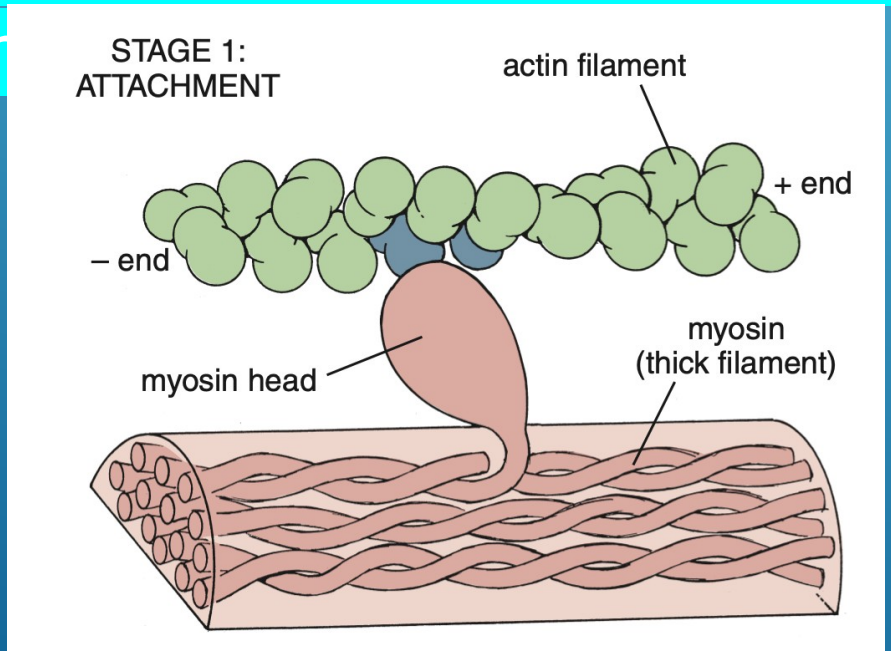


The Contraction Cycle

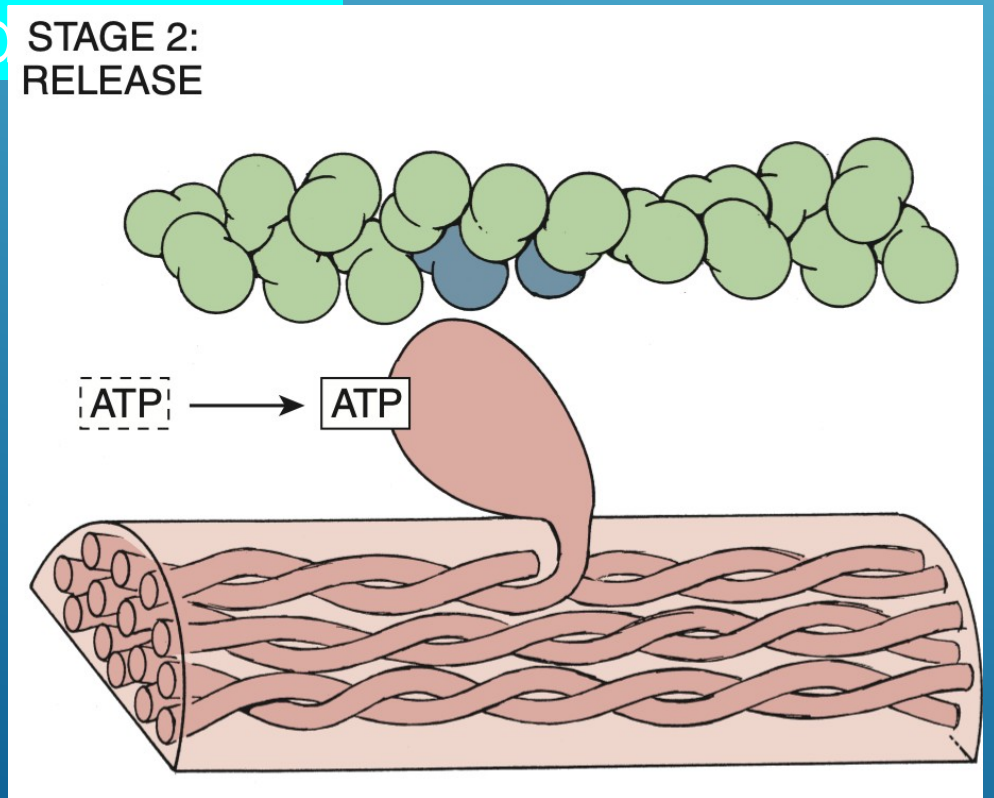
Shortening of a muscle involves rapid contraction cycles that move the thin filaments along the thick filament. Each contraction cycle consists of five stages: attachment, release, bending, force generation, and reattachment.

Attachment is the initial stage of the contraction cycle; the myosin head is tightly bound to the actin molecule of the thin filament ar

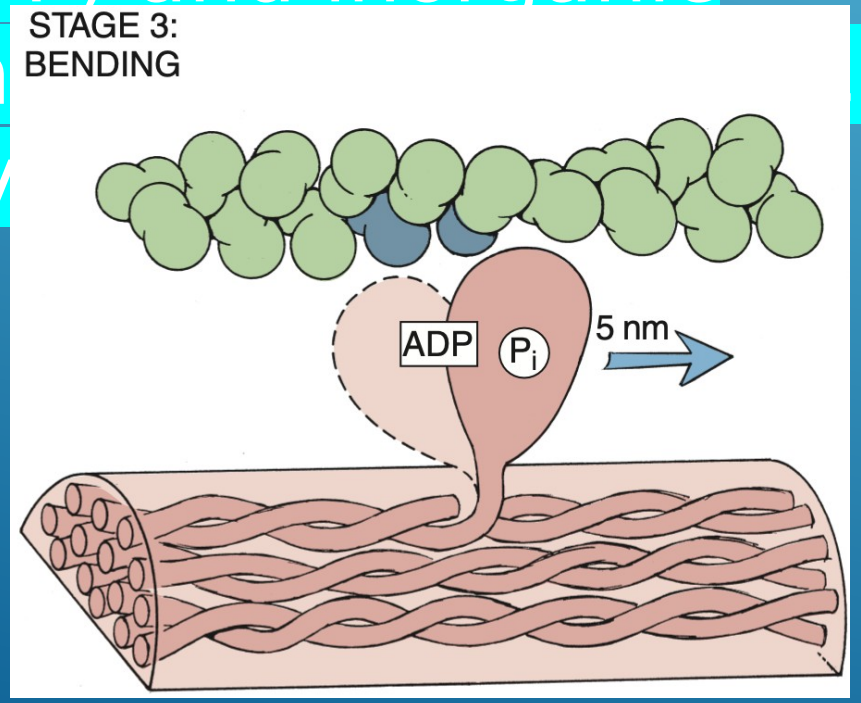
.



Release is the second stage of the cycle; the myosin head is uncoupled from the thin filament. ATP binds to the myosin head and induces conformational changes of the actin-bind

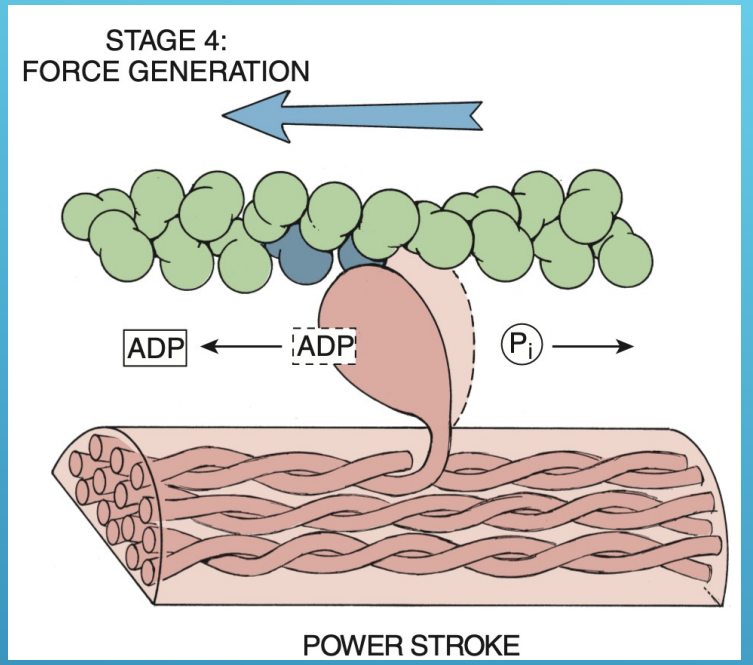


Bending is the third stage of the cycle; the myosin head, as a result of hydrolysis of ATP, advances a short distance in relation to the thin filament. This movement is initiated by the breakdown of ATP into adenosine diphosphate (ADP) and inorganic phosphate; both remain bound to the my



Force generation is the fourth stage of the cycle; the myosin head releases inorganic phosphate and the power stroke occurs.

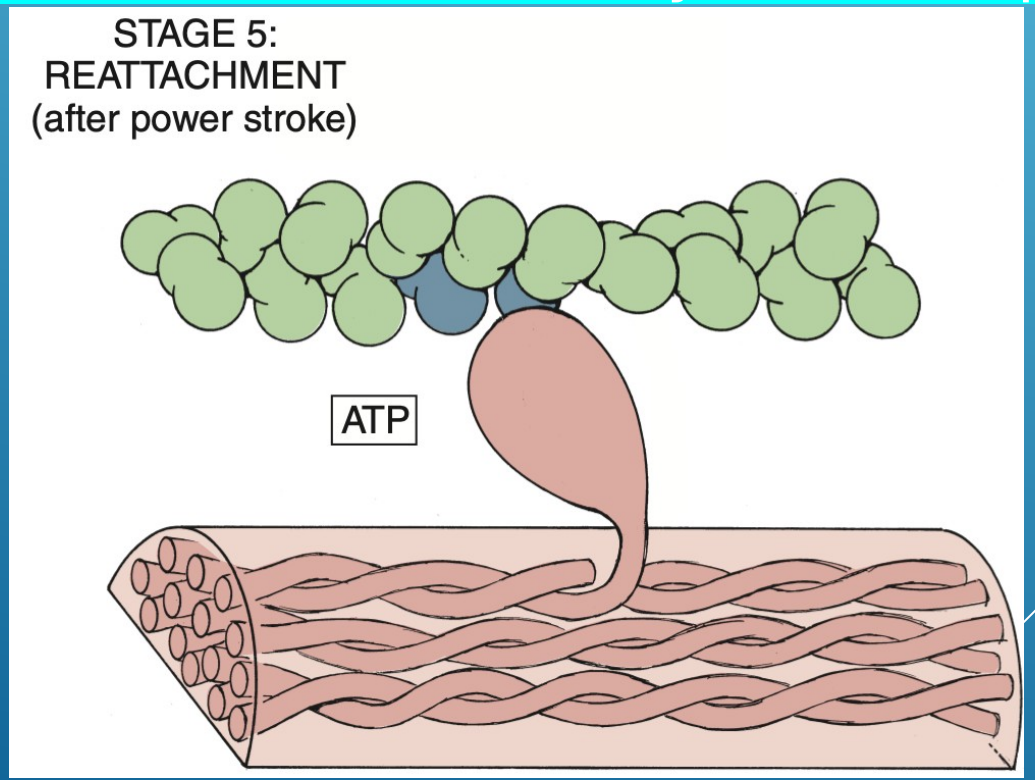
- The myosin head binds weakly to its new binding site on the neighboring actin molecule of the thin filament, causing release of the inorganic phosphate.
- This release has **two effects**. First, the binding affinity between the myosin head and its new attachment site increases.
- Second, the myosin head generates a force as it returns to its original unbent position. Thus, as the myosin head straightens, it forces movement of the thin filament along the thick filament.
- This is the "power stroke" of the cycle. During



Reattachment is the fifth and last stage of the cycle; the myosin head binds tightly to a new actin molecule.

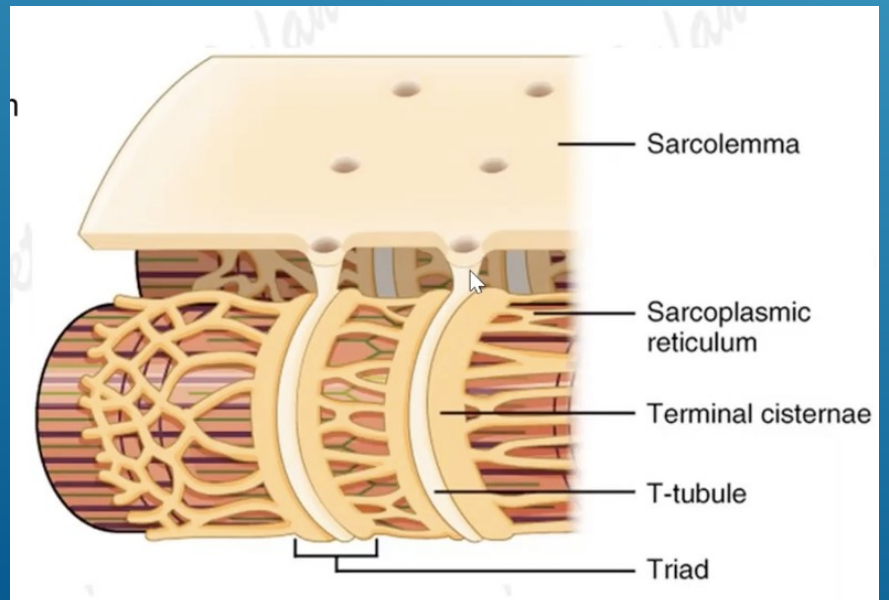
The myosin head is again tightly bound to a new actin molecule of the thin filament and the cycle can repeat.

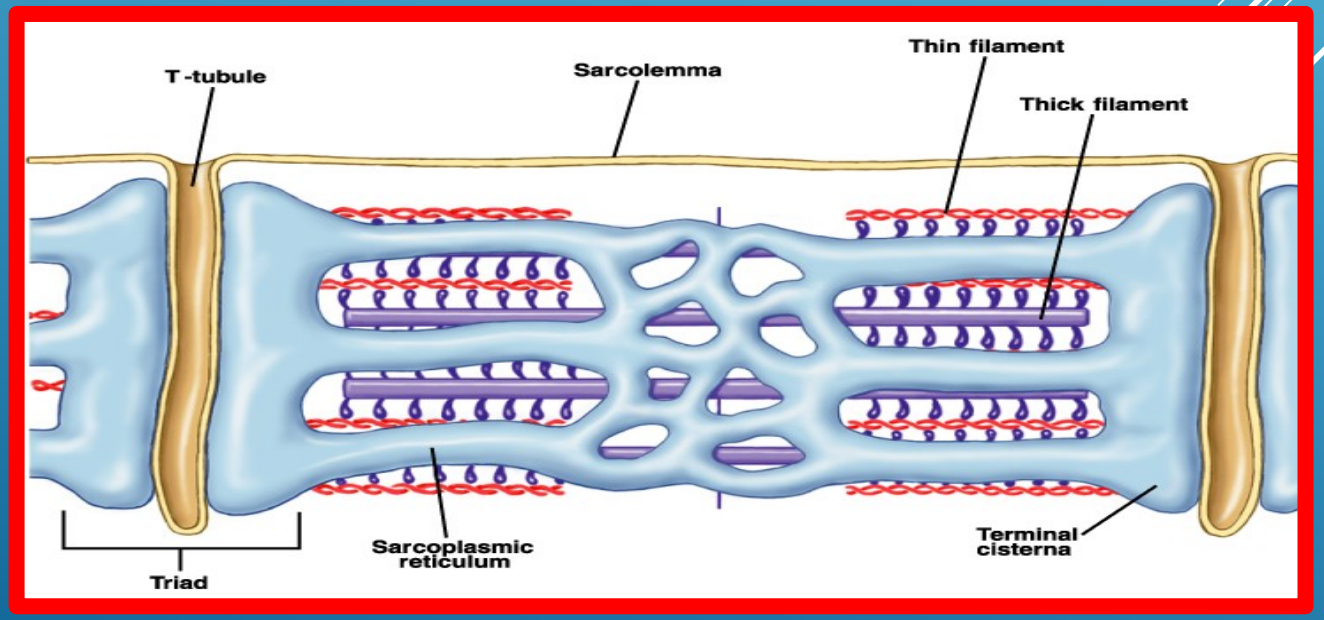
.



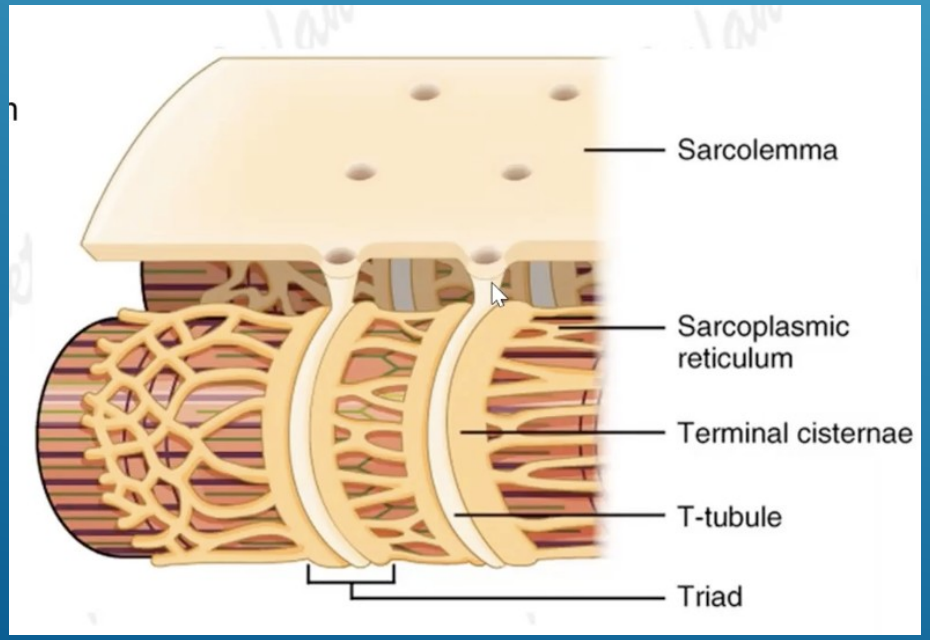
Sarcoplasmic Reticulum And T Tubule System

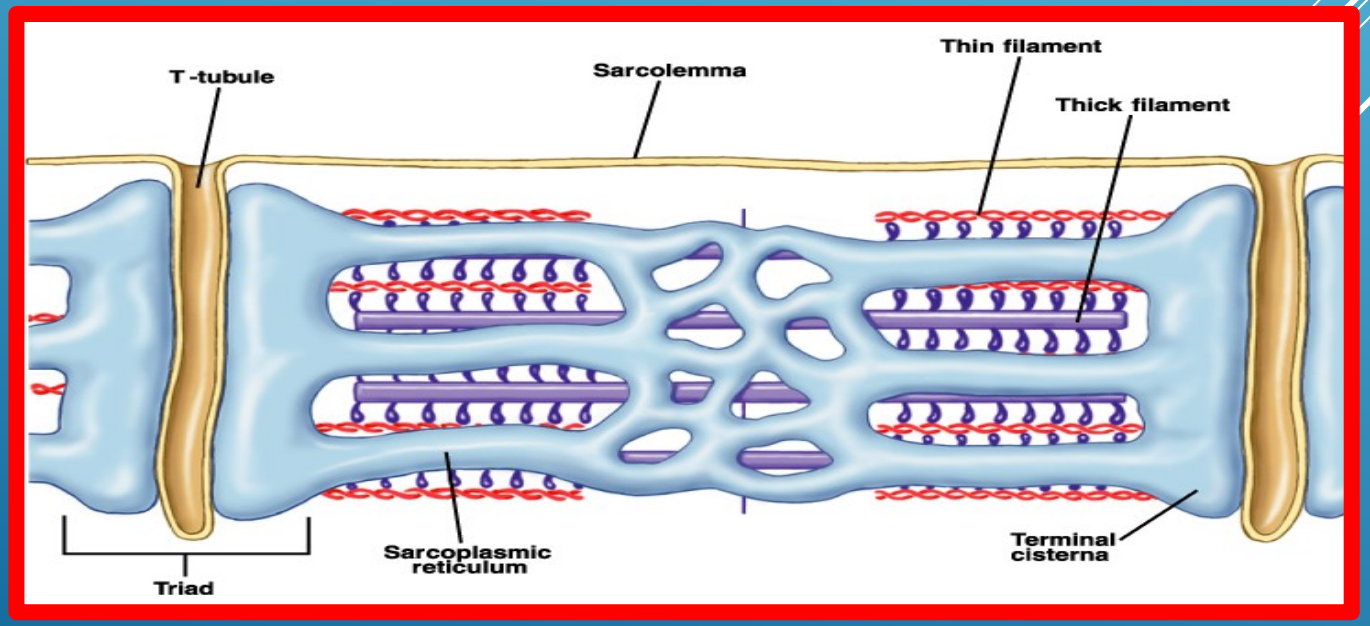
- Ca ++, sarcoplasmic reticulum, and transverse tubule system play a role in the regulation of muscle contraction.
- While Ca++ is necessary for the interaction between actin and myosin, the rapid release and removal of Ca++ are carried out by the cooperation of the **sarcoplasmic reticulum** and **T tubule system**



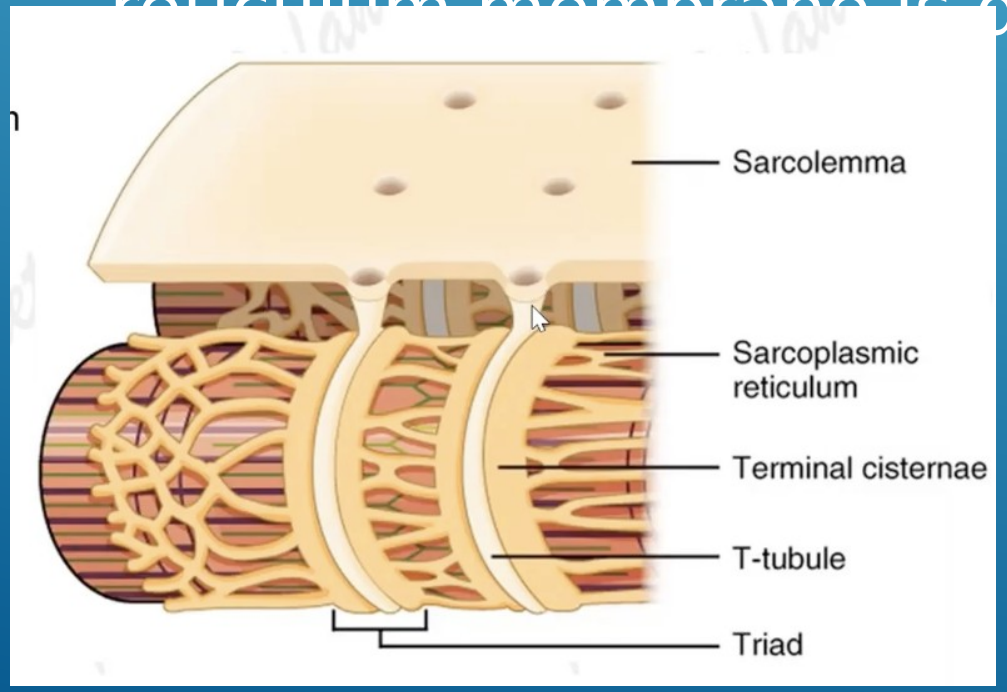


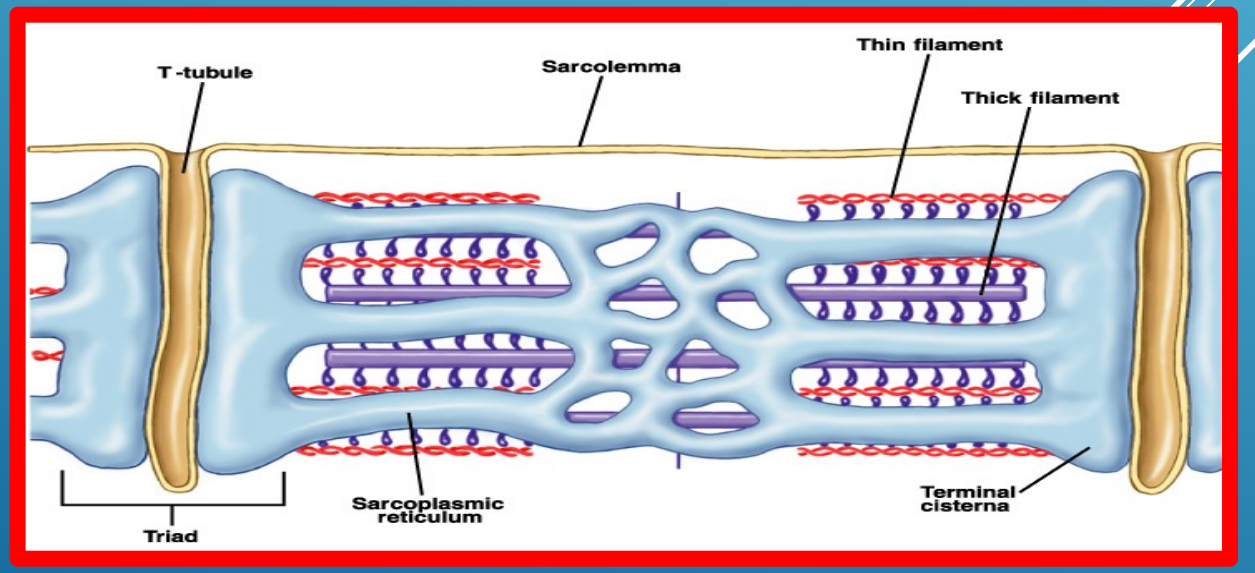
- At the junction of the A and I band, where the two sarcoplasmic reticulum networks meet, the sarcoplasmic reticulum takes a more regular ring shape to form the Terminal cisternae where Ca^{++} is stored.
- There are abundant Ca^{++} release channels in the membrane of the **terminal cisternae**. These channels are required for Ca^{++} release into sarcoplasm.





- **The transverse tubule system (T tubule system)** is tubular structures formed by the invagination of sarcolemma into the sarcoplasma and is located between the neighboring terminal cisternae.
- The complex of lateral sarcoplasmic reticulum cisternae and central T-tubule is called **TRIAD**. The transfer of depolarization in the T tubules to the sarcoplasmic reticulum membrane is done by the Triad.



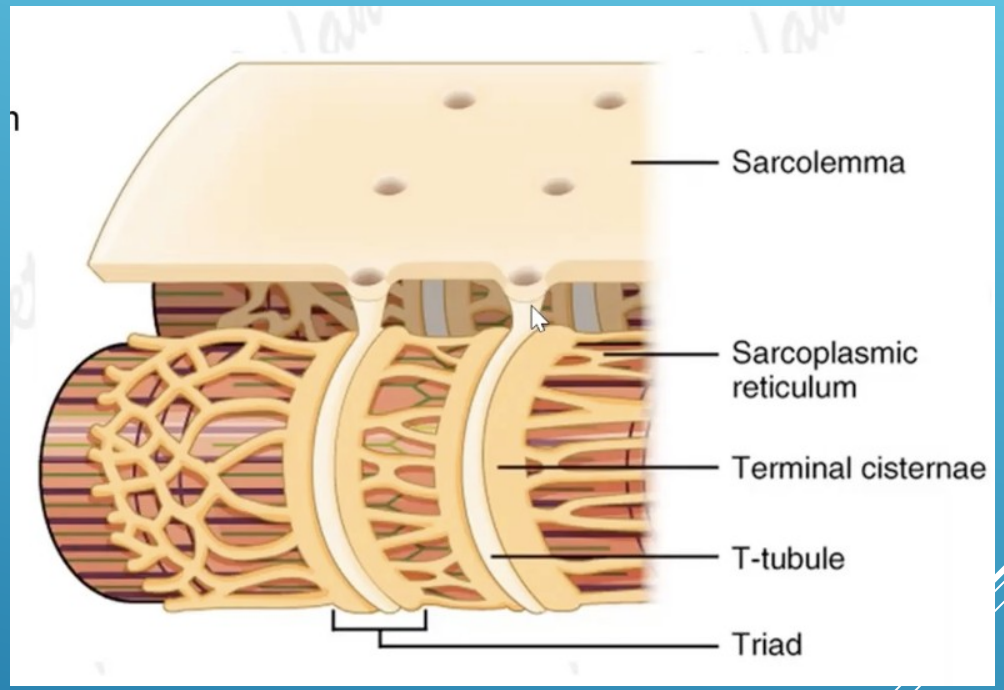


- ***in other words***
- The transverse recesses of the sarcolemma into the cell in skeletal muscle are called T-tubules.

- T tubules (TT) allow the action potential to spread rapidly to myofibrils.

- The sarcoplasmic reticulum terminal cisternae (TS) is located on both sides of the T-tubule.

- The TS-TT-TS triad seen in this region is called the triad.



Triad (at the A-I junction)

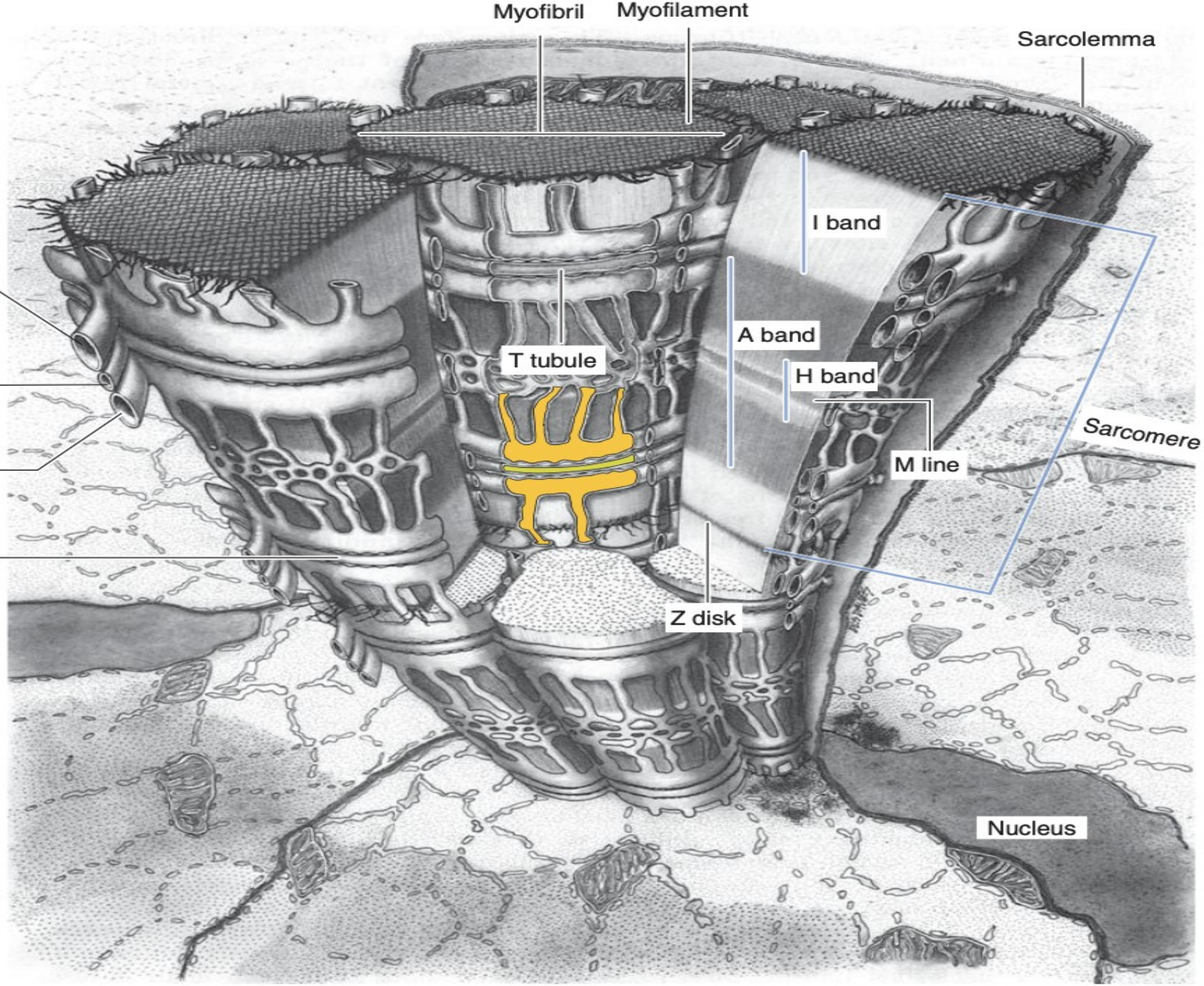
Terminal cisterna of the sarcoplasmic reticulum

Invagination of the sarcolemma (**T tubule**)

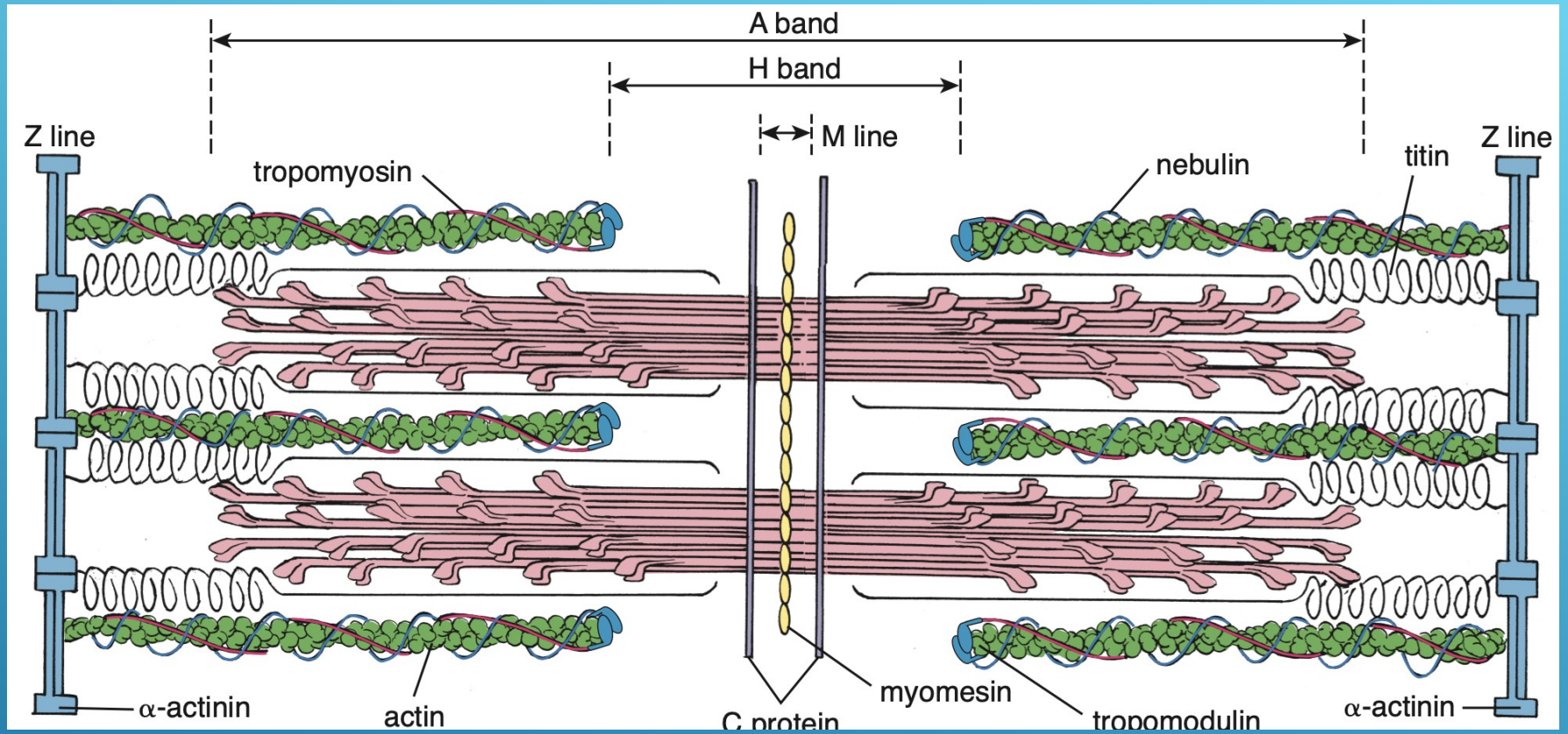
Terminal cisterna of the sarcoplasmic reticulum

The sarcolemma projects long, finger-like processes called **transverse tubules**, or **T tubules**, into the fiber.

T tubules make contact with membranous sacs or channels, the **sarcoplasmic reticulum**.



From Kelly DE, Wood RL, Enders AC: Textbook of Microscopic Anatomy, 18th ed. Baltimore, Williams & Wilkins, 1984.



The interactions of these various proteins maintain the precise alignment of the thin and thick filaments in the sarcomere.

Titin is a large elastic molecule that connects thick (myosin) filaments to the Z line.

α-actinin, bundles thin (actin) filaments into parallel arrays and anchors them at the Z line

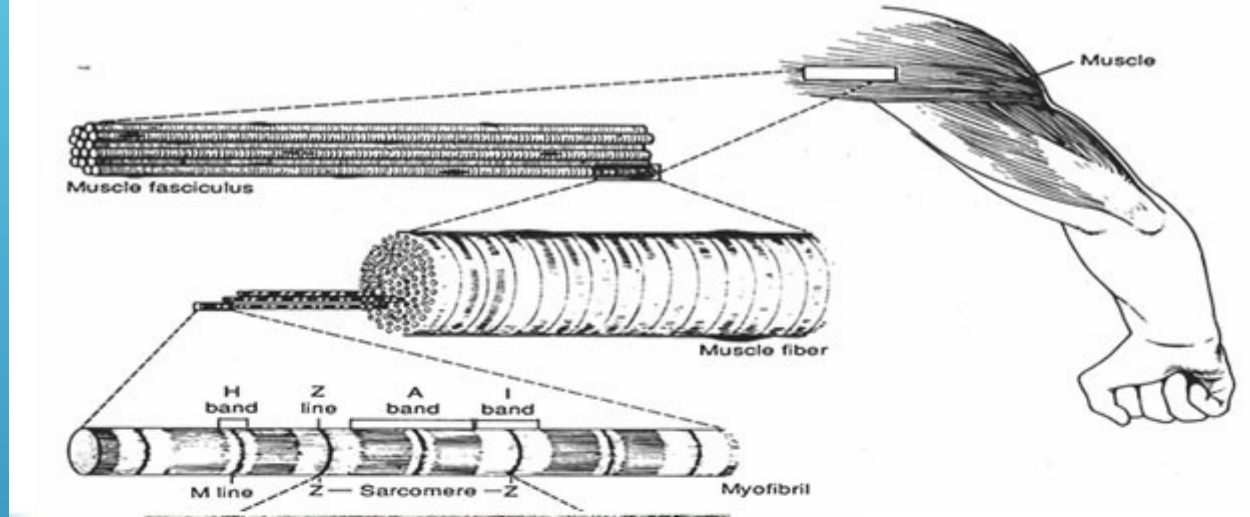
nebulin, an elongated inelastic protein attached to the Z lines that wraps around the thin filaments and assists -actinin in anchoring the thin filament to Z lines

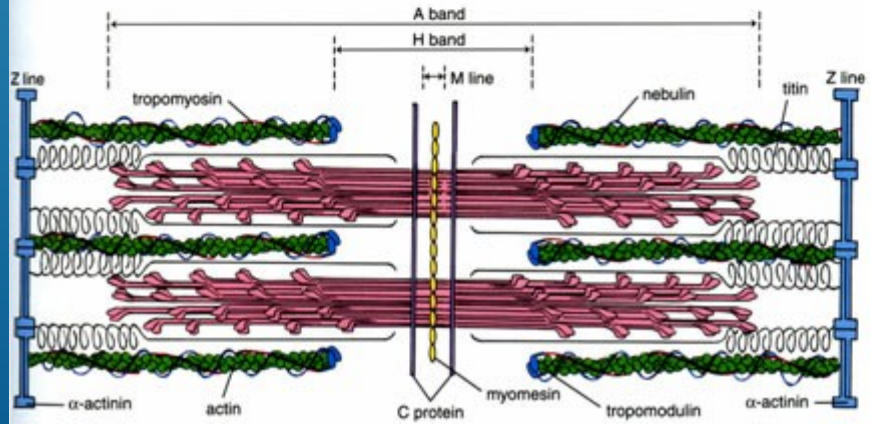
tropomodulin, an actin-capping protein that maintains and regulates the length of the thin filaments

tropomyosin, stabilizes thin filaments and, in association with troponin, regulates binding of calcium ions

Myomesin and C proteins, myosin-binding proteins that hold thick filaments in register at the M line.

ORGANIZATION OF SKELETAL MUSCLE FIBERS THE SARCOMERE…





Contractile unit of striated muscle

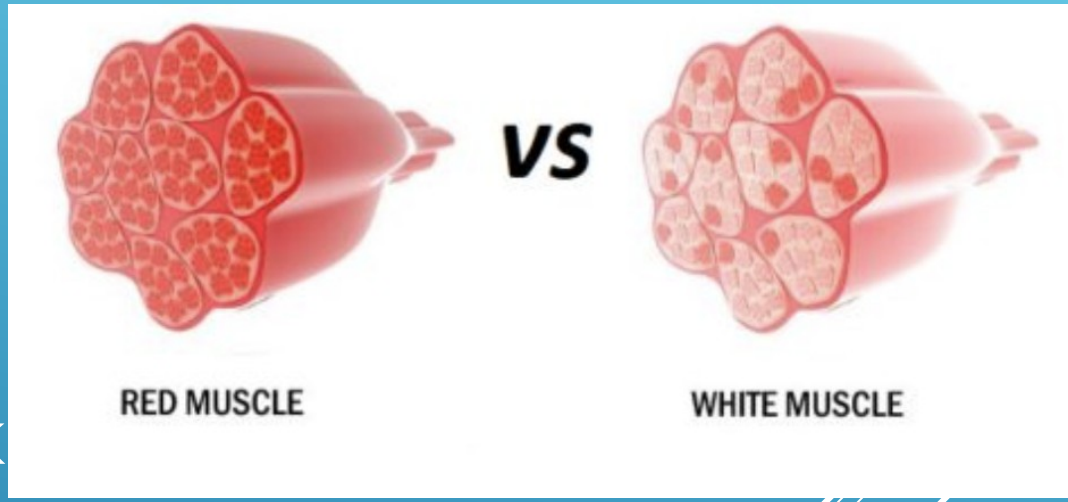
- Structures between Z lines
  - 2 halves of I bands
  - A band
  - H zone
  - M line (“middle of the disc”)
  - Myofilaments
    - Actin
    - Myosin
  - Other structural proteins
    - Titin (myosin-associated)
    - Nebulin (actin-associated)
    - Myomesin (at M line)
    - α actinin (at Z line)

Other Structures in the Sarcoplasma

- **Mitochondria (Sarcosomes):** They are numerous, just under the sarcolemma, near the nucleus ends. It is also found scattered among myofibrils. The number is higher in fast twitch muscles. It is the source of ATP.
- **Glycogen:** During muscle contraction, they help to store the energy that will allow movement. It can be demonstrated with the appropriate paint.
- **Lipid:** It is a storehouse of energy. Fatty acids are transported to the cell by lipoproteins and stored in fat droplets.

Fiber Types in Skeletal (Striped) Muscle

- **Three types of skeletal muscle fibers—red, white, and intermediate—can be identified by color in vivo.**
- There are three types of fibers in skeletal muscle called red and white fibers, and most skeletal muscle consists of a mixture of these two fibers.
- **Myoglobulin:** It is the pigment (dark red) that gives the muscle its color. It binds oxygen, like an oxygen reservoir. When the need for oxygen of the muscle increases, its oxygen is released.



red fibers (involved in maintenance of posture), white fibers (responsible for rapid contraction), and intermediate fibers (a combination of the characteristics of red and white fibers)

Red Fibers

- It is dark red in color as it has a lot of myoglobulin and cytochromes.
- Since energy is mainly provided by oxidative phosphorylation, its **contraction slow but long-lasting shrinking.**
- They are smaller in diameter than white fibrils.
- Oxygen is rich from the vein because it is used in excess.
- They have abundant mitochondria.
- They are resistant to fatigue and therefore suitable for prolonged muscular activity.

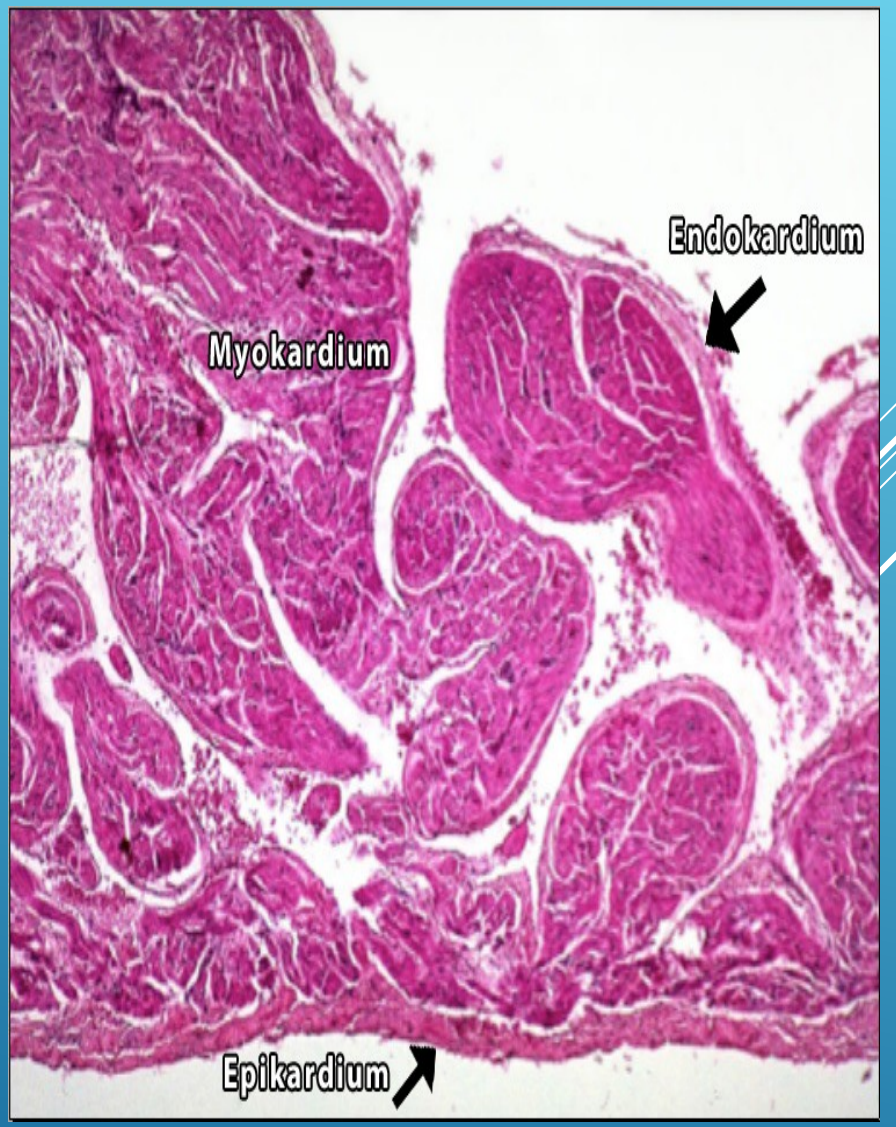
White fibers

- They are muscles rich in large diameter myofibril.
- Mitochondria and myoglobulin are few, pale in color.
- Since energy is mainly provided by anaerobic glycolysis, **contraction ıs fast but short-term.**
- They contract quickly and are generally responsible for movement.

CARDIAC MUSCLE

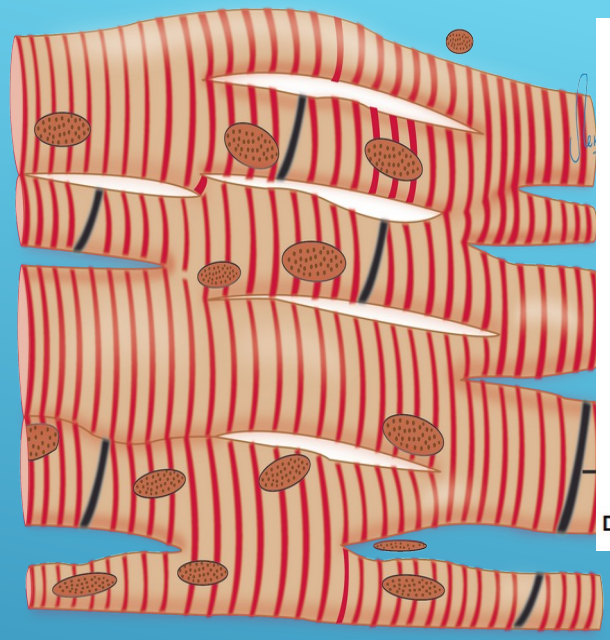
- Shows striated appearance It has a single nucleus in the center.
- Muscle fibers are surrounded by the endomysium layer.
- Contraction is **Involuntary**
- **Branched cells**

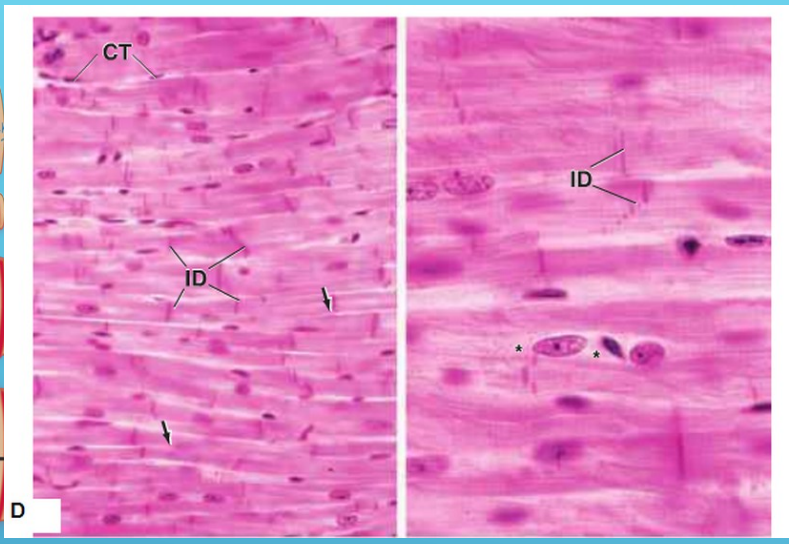
- Cardiac muscle fibers are like skeletal muscle due to the transversely striated myofibrils;
- Involuntary contraction,
- muscle fiber contains a single nucleus,
- and the nucleus is located in the center of the fiber, resembles a smooth muscle.

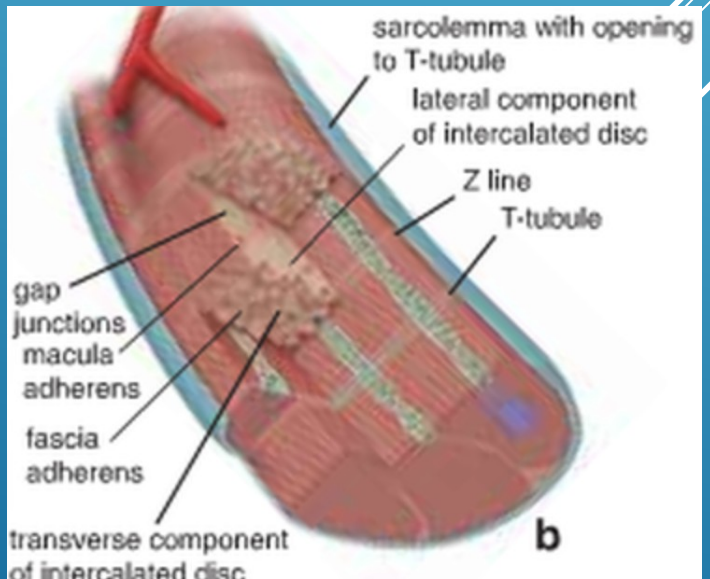


- A unique and distinguishing characteristic of cardiac muscle is the presence of dark-staining transverse lines that cross the chain of cardiac cells at irregular intervals.

- These lines are called intercalated discs and this discs represent the interface between adjacent muscle cell where many junctional complexes are present.
- This discs have many desmosomes(Maculae adherents), Gap junctions and fascia adherents (adhering junction)

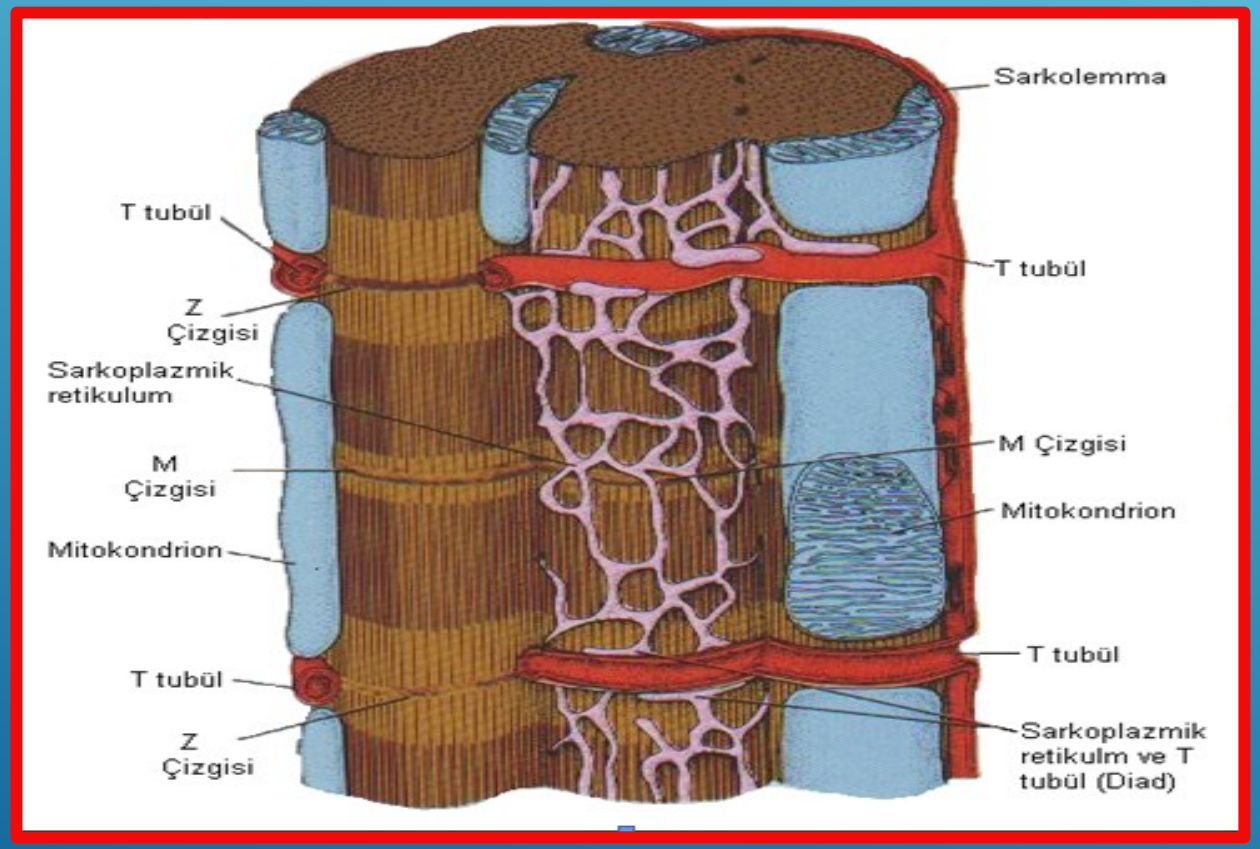






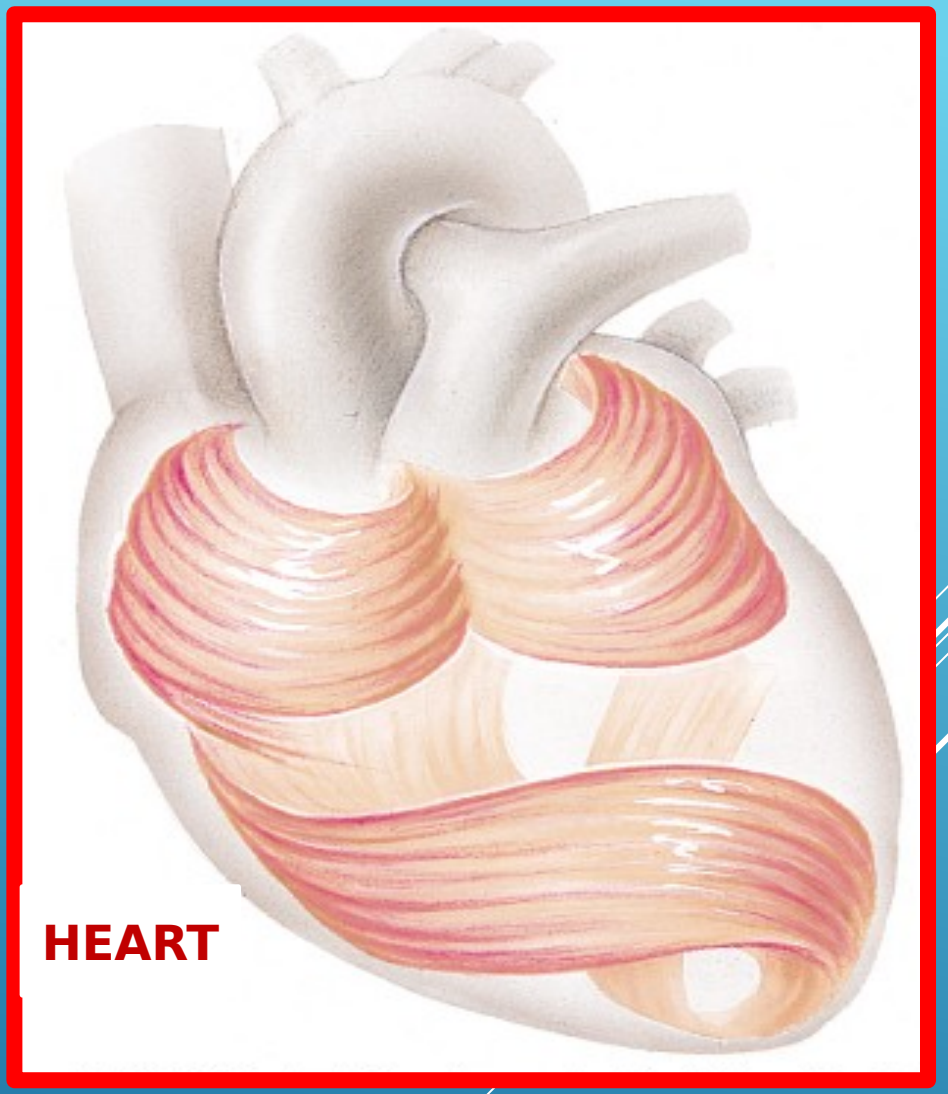
Intercalated disc contain specialized cell-to-cell junctions between adjoining cardiac muscle cells:

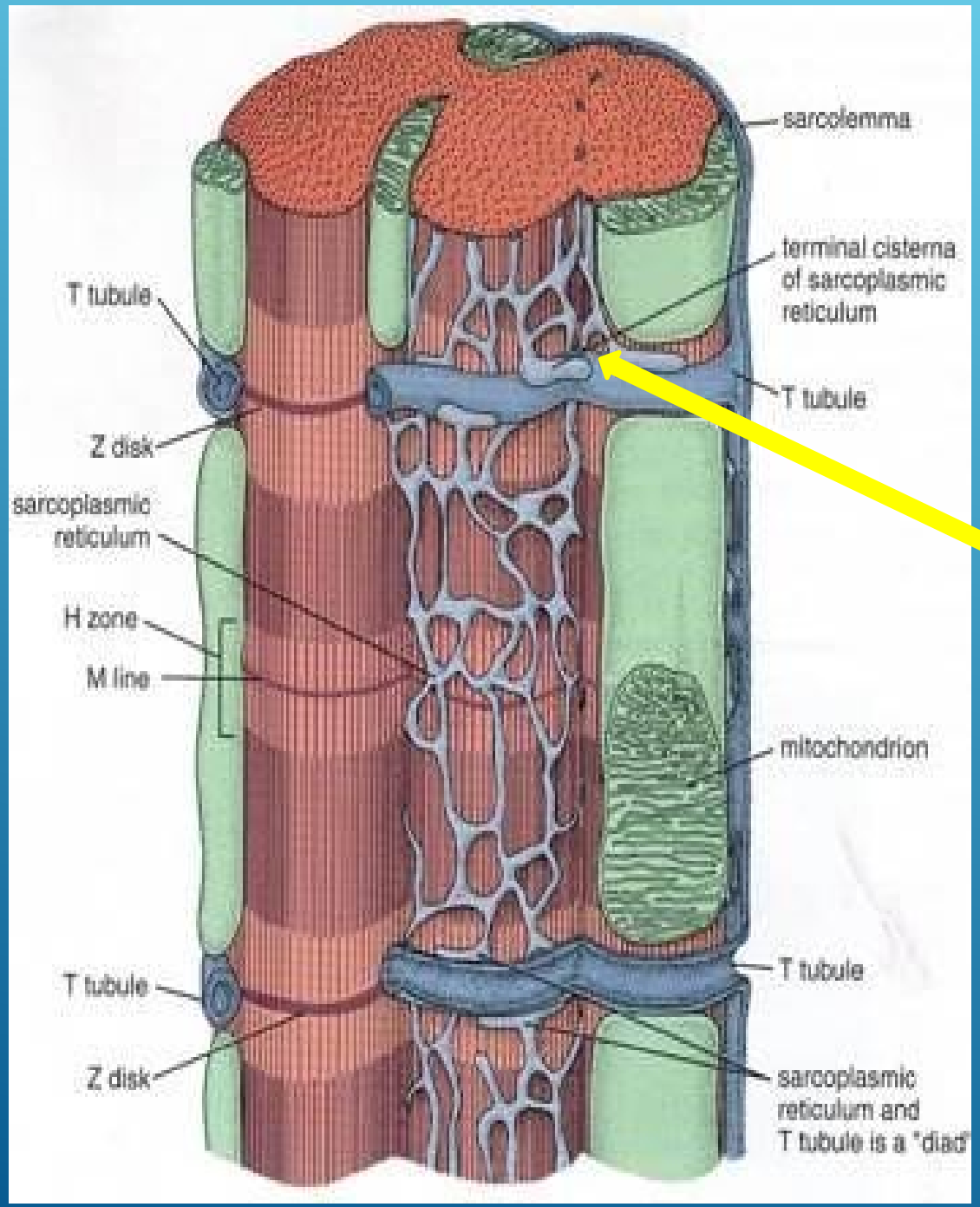
Sarcoplasmic Reticulum And T Tubule System



- It does not have a regular system as in skeletal muscle.
- T-tubules are more, and the number of reticulum is less.

- Cardiac T tubules are located in the Z band level, not at the A-I junction like in mammalian skeletal muscle.





- There are no Triads in cardiac muscle as T tubules in cardiac cells are usually with only one lateral extension of the SR cisternea.
- Muscle cell has **DIAD** that consists of T Tubule and an SR cistern .

Other Structures in the Sarcoplasma

- Cardiac muscle cells contain a large number of mitochondria. These occupy more than 40% of the cytoplasm volume. In skeletal muscle, this ratio is only 2%.
- Fatty acids, which are carried to the cardiac muscle cells by lipoproteins, are the main fuel of the heart.
- Fatty acids are stored ın the shape of the trıglycerides IN the cytoplasm of cardiac muscle cells.
- There is less glycogen. This provides the necessary energy by breaking down into glucose in case of stress.

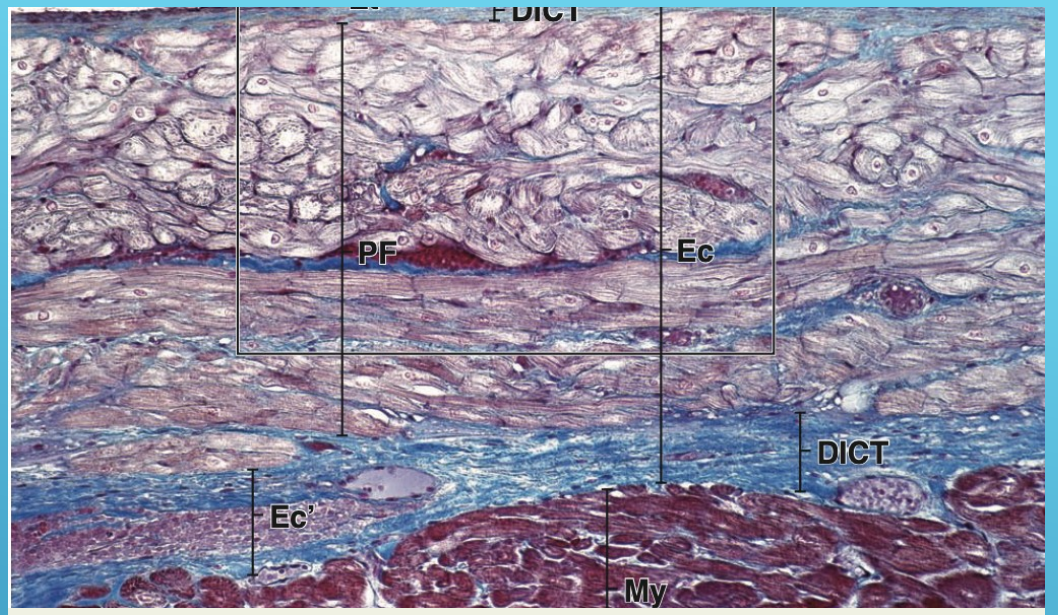
Type of the Cardiac Muscle

- Two different muscle cells are seen, namely atrial and ventricular. The arrangement of myofilaments in both types of heart muscle is generally the same except for a few differences.
- **The atrial muscle** contains very few T tubules and its cells are smaller. These atrial granules contain large molecular weight precursors of a hormone called atrial natriuretic factor. Atrial natriuretic factor causes sodium and water loss by acting on the kidneys.
- **Ventricular cardiac muscle** fibers mostly have T-tubules and are non-granular.

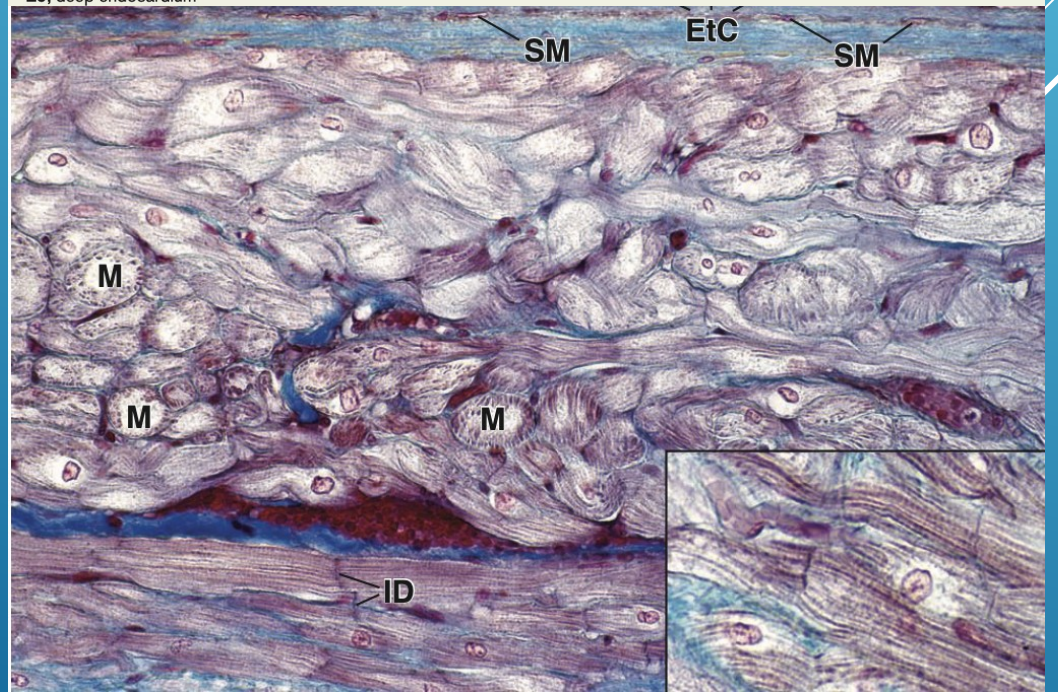
A specialized type of cardiac fiber is the Purkinje fiber, a glycogen-rich cells with fewer myofibrils, involved in conductivity.

The terminal fibers of the conducting system of the heart are specialized, glycogen-rich **Purkinje fibers**. Compared with the contractile fibers, Purkinje fibers are larger, paler-stained, and contain fewer myofibrils

Purkinje fibers can be found beneath the endocardium lining the interventricular septum. Purkinje fibers can be distinguished from regular cardiocytes by their location, their larger size, and lighter cytoplasmic staining (glycogen content).

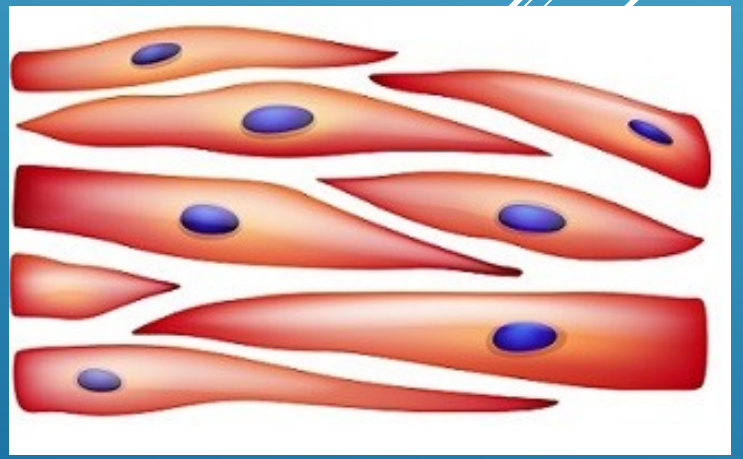


A, atrial wall
AS, atrioventricular septum
DICT, dense irregular connective tissue
Ec, endocardium
Ec', deep endocardium
Et, endothelium
EtC, endothelial cells
ID, intercalated discs
M, myofibrils
My, myocardium
PF, Purkinje fibers
SM, smooth muscle cells
V, ventricular wall

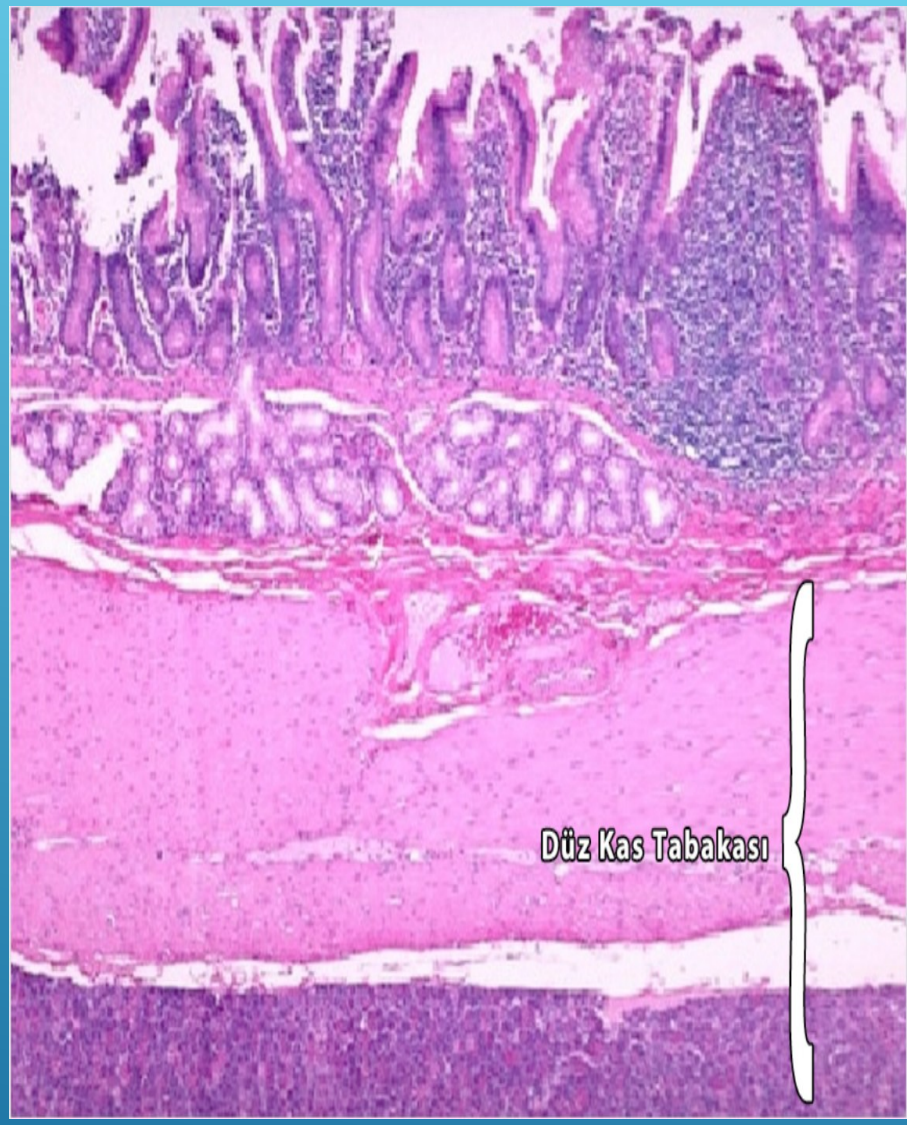


SMOOTH MUSCLE

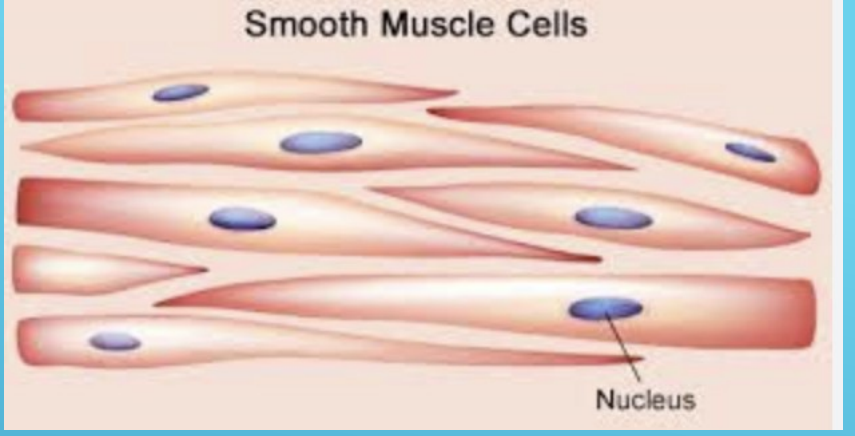
- They usually consist of shuttle/spindle-shaped cells with a single nucleus in the center, located in internal organs and blood vessels.
- Their contraction and relaxation are slowly.
- Their contractions are involuntary.
- T tubules are absent and the sarcoplasmic reticulum is not well developed.

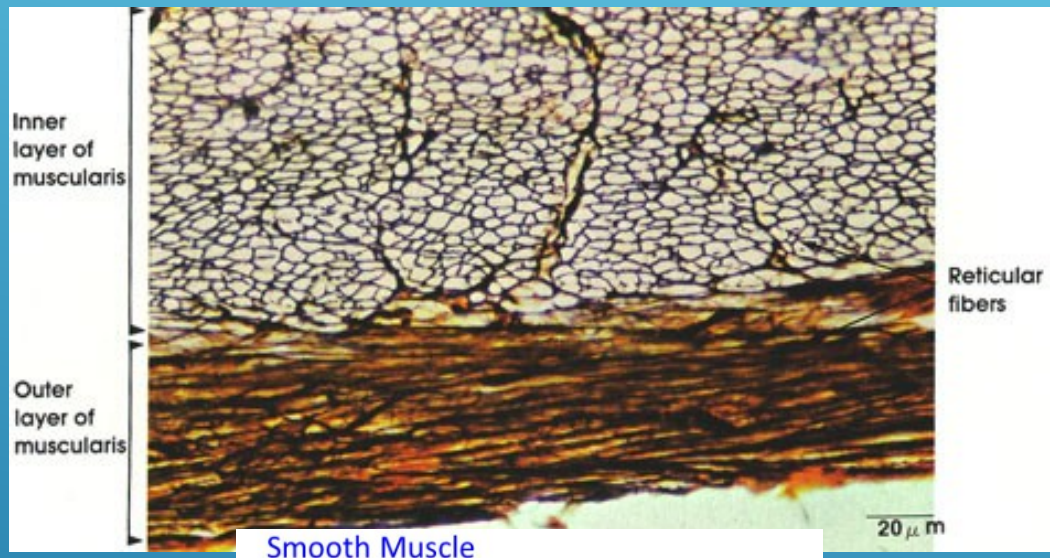


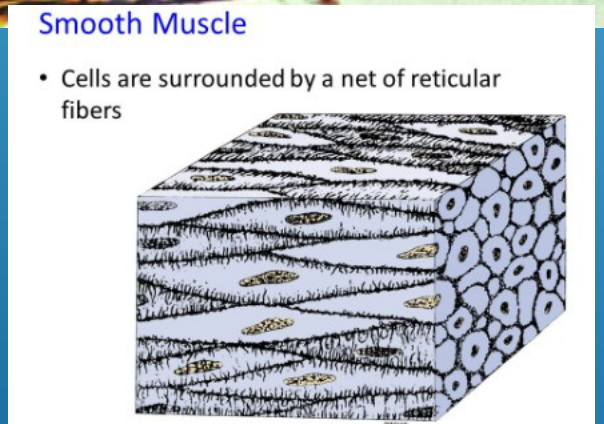
- Each muscle fiber contains actin and myosin protein, but their configuration is different from the other two types of muscle.
- These filaments are obliquely and cross-structured in the cytoplasm. For this reason, they are observed as straight and without bands.
- Smooth muscles can contract due to neural stimulation, hormonal stimulation, or regression.



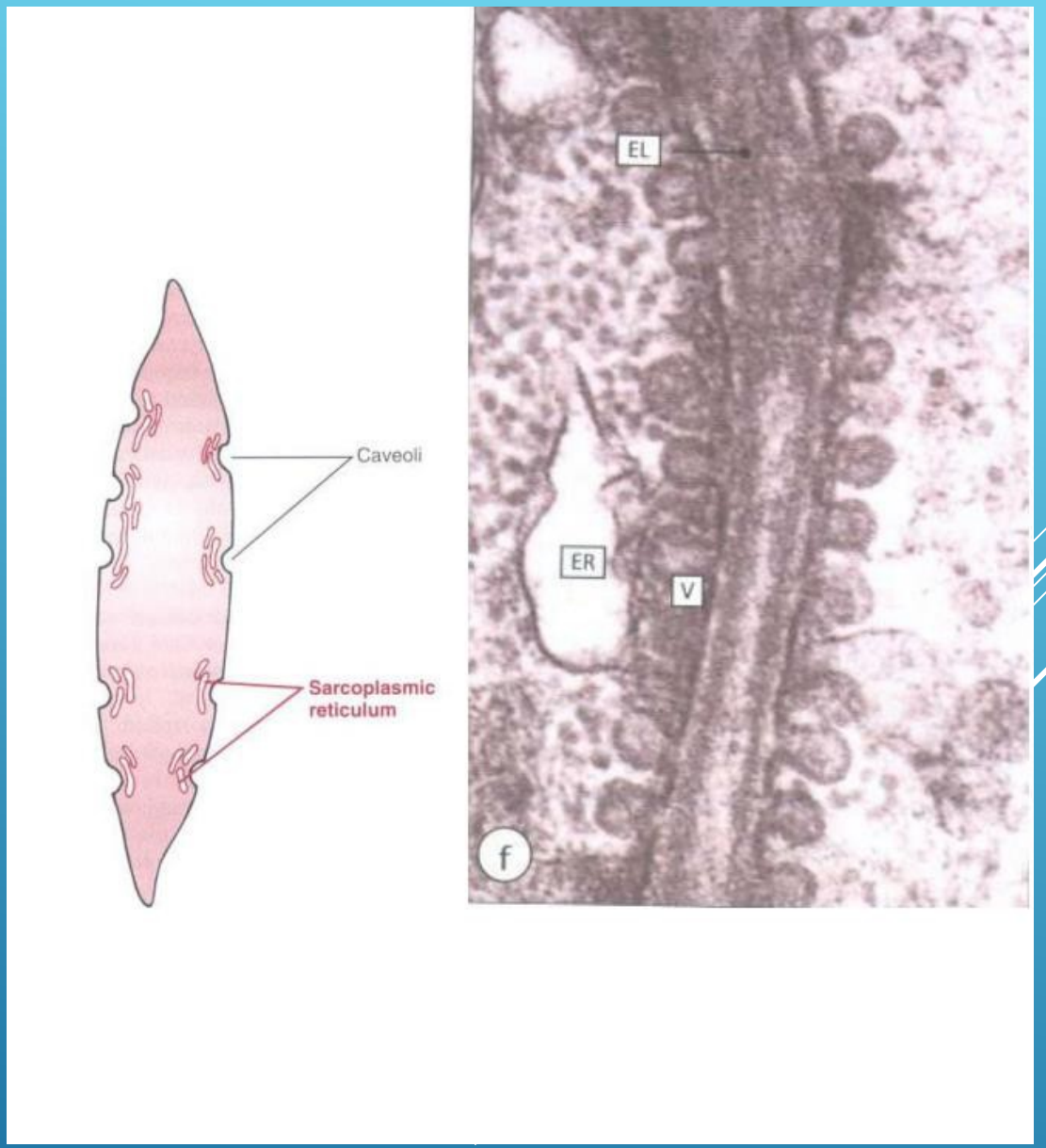
- The narrow section of a cell is adjacent to the wide section of the neighbouring cell.
- Around each cell are a basal lamina and a network of reticular fibers.
- This network plays a role in transforming the force generated by each smooth muscle fiber into collective action, such as peristaltic movements in the intestines.







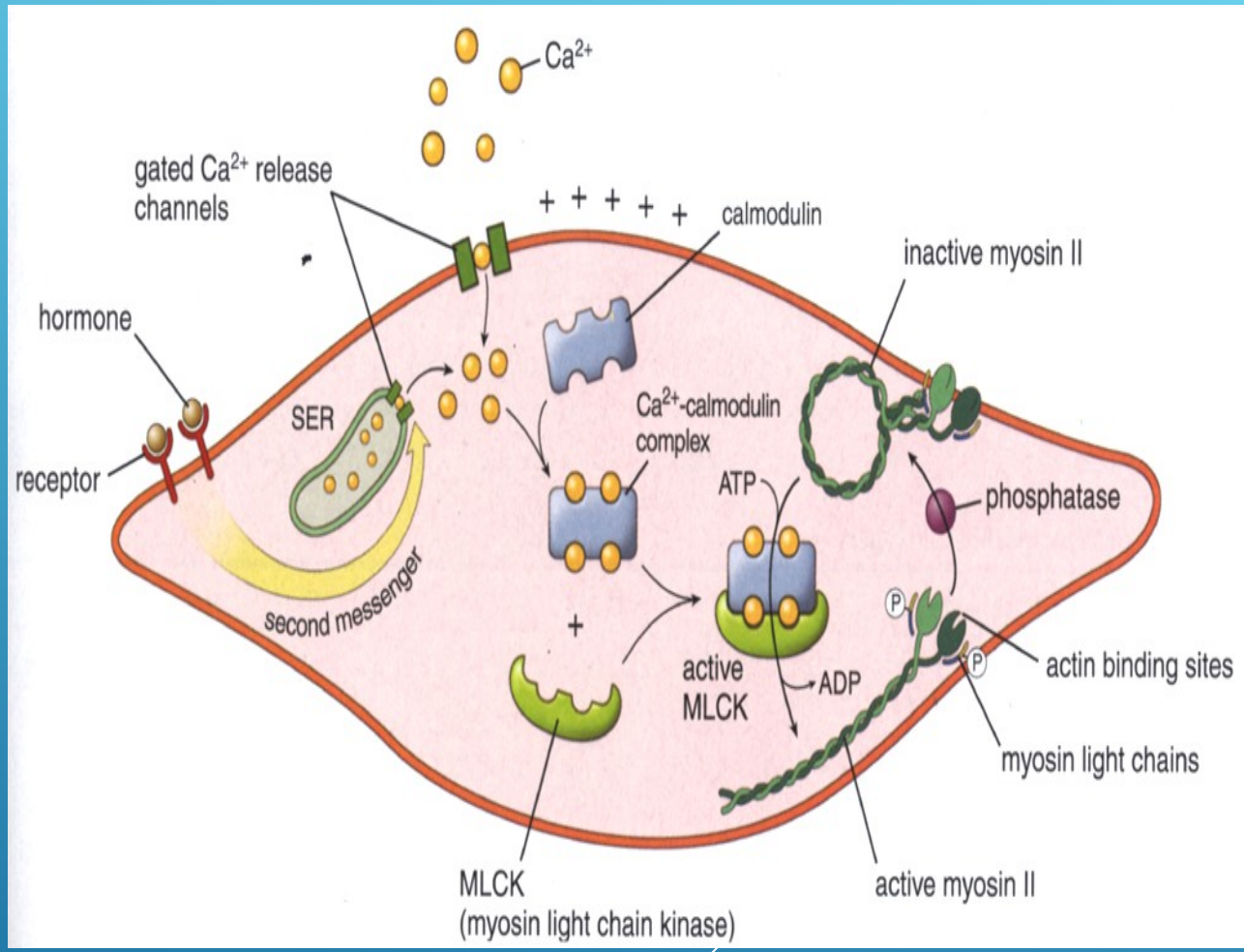
- Due to the absence of T tubules, Ca^{++} is provided from the short membrane indentations on the cell surface called caveola.
- The intermediate filaments in these cells are located in structures called dense bodies that serve as Z lines.



SMOOTH MUSCLE CONTRACTION:

ALSO CA+ DEPENDENT, BUT MECHANISM IS DIFFERENT THAN STRIATED MUSCLE

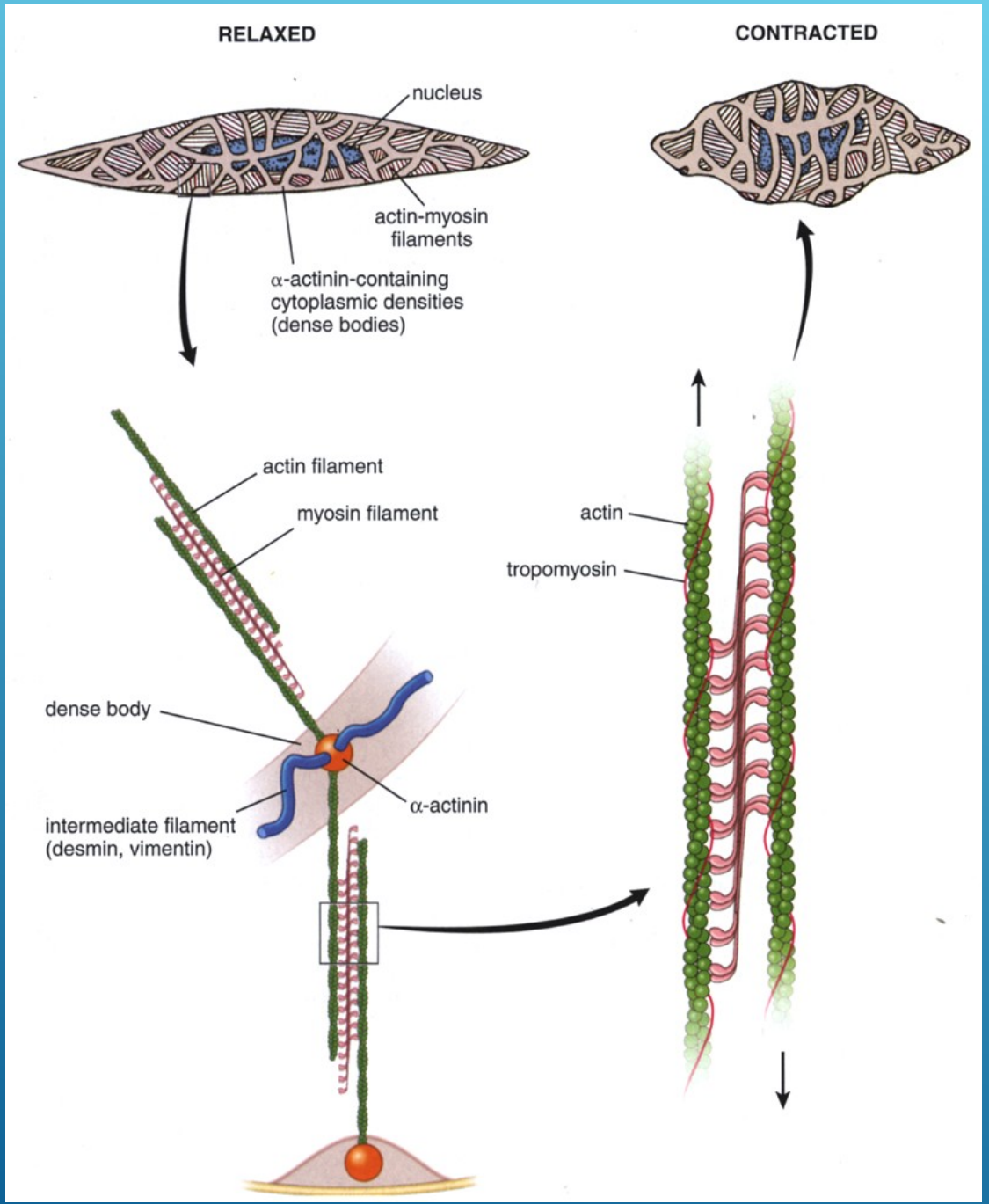
1. Ca^{2+} ions released from caveloae/SER and complex with calmodulin
2. Ca^{2+} -calmodulin activates myosin light chain kinase
3. MLCK phosphorylates myosin light chain
4. Myosin unfolds & binds actin; ATP-dependent contraction cycle ensues.
5. Contraction continues as long as myosin is phosphorylated.



Triggered by:

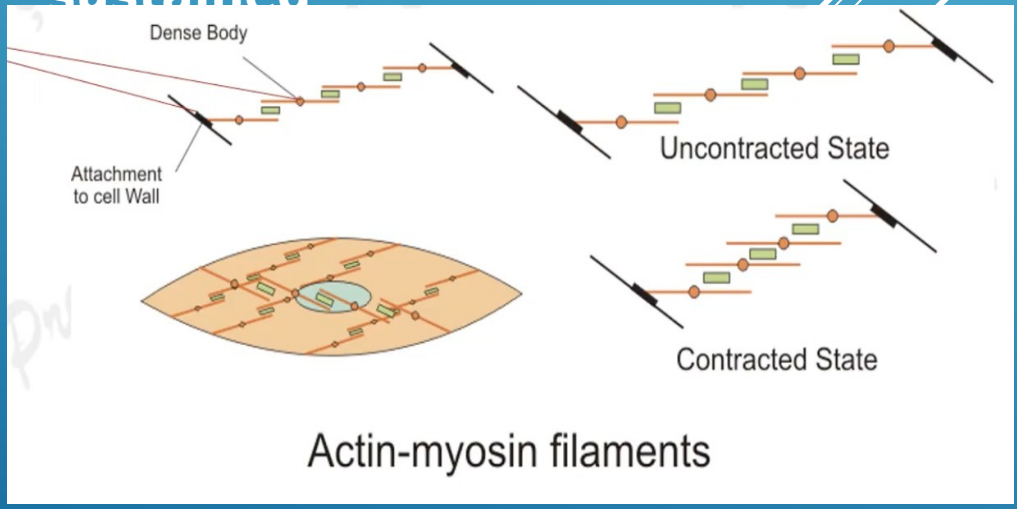
- Voltage-gated Ca+ channels activated by depolarization
  - Mechanical stimuli
  - Neural stimulation

- Ligand-gated Ca+ channels



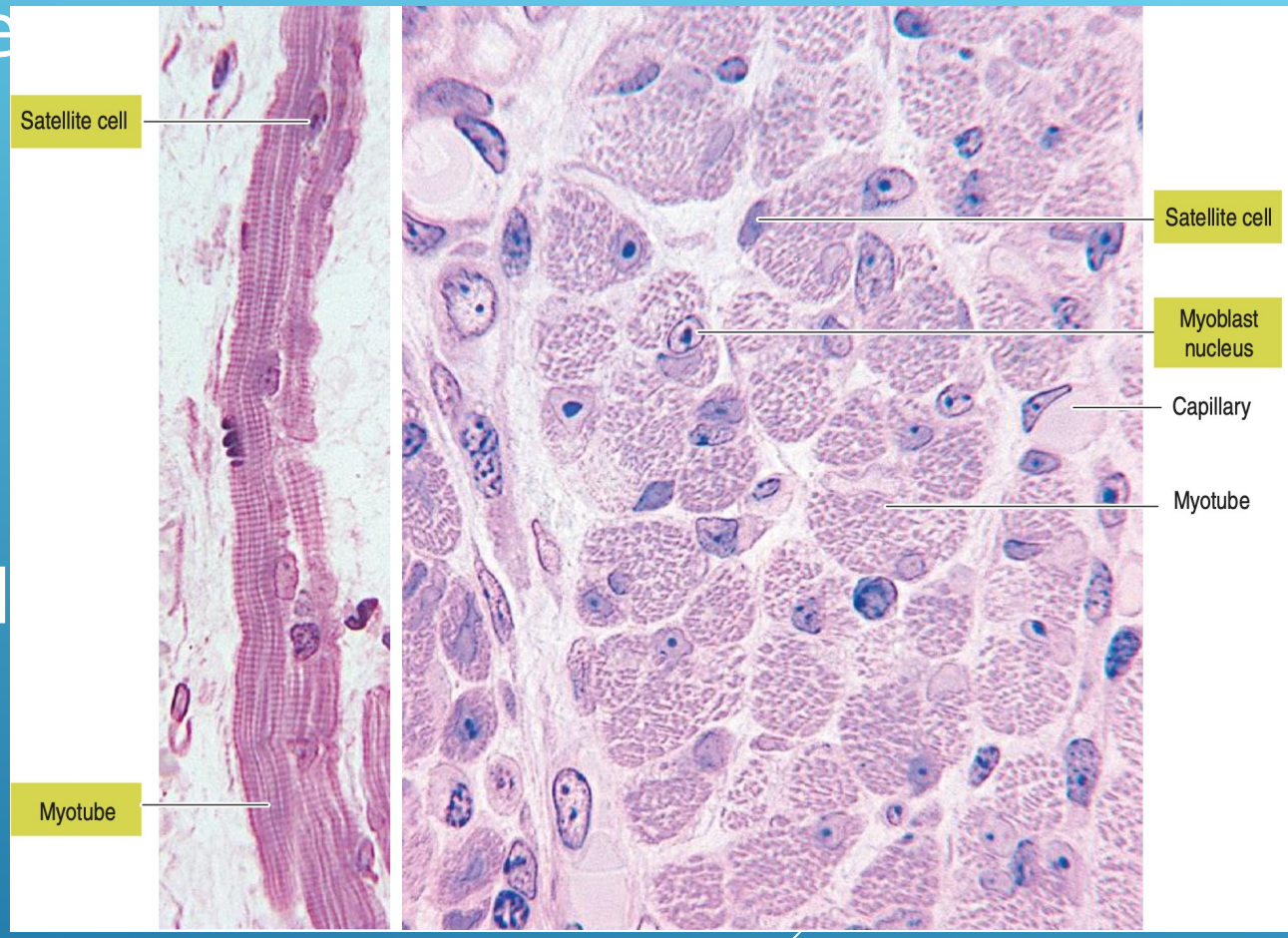
Mechanics of Smooth Muscle Contraction

- Dense bodies are analogous to Z lines (plaques into which actin filaments insert)
- Myosin heads oriented in "side polar" arrangement
- Contraction pulls dense bodies together
- Contraction is **slow** and **sustained**



REGENERATION OF MUSCLE TISUE

- Satellite cells in skeletal muscle are responsible for tissue regeneration, but the regenerative ability is very low in skeletal muscle.
- Satellite cells are not found in the heart muscle, the damaged area is filled with connective tissue.
- Smooth muscle cells have the highest ability to regenerate and are renewed by mitosis.



	Skeletal muscle	Cardiac muscle	Smooth muscle
Contraction	Voluntary	Involuntary	Involuntary
Sarcomer	Available	Available	unavailable
Nucleus	Multinucleated, located in the periphery	Single nucleated, located in the center	Single nucleated, located in the center
Sarcoplasmic reticulum	well-developed	underdeveloped	Less
T Tubule	Available, TRIAD	Available, DIAD	unavailable
Rejeneration	Limited	None	High
Special feature	Cylindrical cells, transverse streaking is observed	Branched cells, intercalated disc	Spindle-shaped, no transverse streaking

THANK YOU